Master Project Work HS 2018

MASTER PROJECT WORK

Flexibility in parking spaces to take into consideration the future need of electrical charge facilities

Author: Sandra Schärer, ETH-Nr. 13-932-389

Advisors: Prof. Dr. Bryan T. Adey
Dr. Claudio Martani

Zürich, 17.12.2018

ETH Zürich
Institut für Bau- und Infrastrukturmanagement
Professur für Infrastrukturmanagement
Professor Dr. Bryan T. Adey

Eidgenössische Technische Hochschule Zürich
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Abstract

Facilities, which have a long life span, are difficult to design in a way that they fulfill the desired level of service (LOS) throughout this period. Within this long period the required level of service might change, since there are many uncertainties. These uncertainties can be counteracted with the implementation of a flexible design for the facility. This flexible design allows the facility to be adaptable towards possible future situations, which can lead to a higher benefit for the facility's owner over the examined of time. Therefore, the flexibility and the stability of an initial design for a facility should be adequately considered regarding the possible scenarios and their corresponding probability to occur.

In this project work a newly developed methodology is used to determine the optimal initial design of a parking facility regarding the uncertain future need of electrical charge facilities due to the upcoming of electrical vehicles. Therefore, different flexible and non-flexible initial implementation options for a parking garage are defined. With the modelling of certain key parameters the future need of electrical charge facilities for electrical vehicles within the parking garage is predicted. The benefit of each initial implementation design is estimated and compared to each other. The methodology is tested and applied on a real case study, whereas a time period of 60 years is considered. The most beneficial and most stable implementation design is a flexible one, which implies the traditional implementation of the parking garage with the ability to implement step-wise the required electrical charge facilities as the demand is rising.

Zusammenfassung

Es ist schwierig Einrichtungen mit einer langen Lebensdauer zu erstellen, sodass während der gesamten Zeitspanne die gewünschte Qualität gewährleistet werden kann. Da die Zukunft mit vielen Unsicherheiten behaftet ist, können sich die Qualität und die Qualitätsanforderungen für eine Einrichtung in diesem Zeitraum ändern. Um diesen Unsicherheiten entgegenzuwirken, besteht die Möglichkeit die Infrastruktur mit einem flexiblen Design zu erstellen. Diese Flexibilität ermöglicht die Anpassungsfähigkeit der Infrastruktur bezüglich möglicher zukünftiger Szenarien, was wiederum zu einem höheren Nutzen über den ganzen Zeitraum für den Eigentümer führen kann. Darum sollte beim Entwerfen und Erstellen einer Infrastruktur diese Flexibilität bezüglich möglicher Szenarien und deren Eintrittswahrscheinlichkeit berücksichtigt werden.

In dieser Projektarbeit werden flexible und nicht-flexible initiale Erstellungsvarianten für eine Parkgarage definiert. Mit der Modellierung von bestimmten Parametern wird die zukünftige Nachfrage nach elektrischen Ladestationen für Elektroautos in der Parkgarage abgeschätzt. Der Gewinn jeder Erstellungsvariante wird ermittelt und miteinander verglichen. Die gewinnbringendste und stabilste Variante ist eine flexible Variante, welche die normale Erstellung der Parkgarage besagt, mit der Ergänzung, dass die Parkgarage schrittweise mit elektrischen Ladestationen für jeden Parkplatz aufgerüstet werden kann, sobald die Nachfrage steigt.

Acknowledgement

Thank you to Prof. Bryan Adey for letting me elaborate this master project work at the IB Institute. Thank you to Dr. Claudio Martani for the enormous supervision during my project work and the motivational discussions. Thanks to the company pom+ for the providing of the case study of this project work.

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1 Introduction

Civil infrastructures have a lifespan of several decades. It is known, that in this long time period the environment around the infrastructure and the needs of the people might going to change. But it is highly uncertain how the needs are going to change and how much this will affect the infrastructure system. This uncertainty has a huge impact on the initial implementation of a long-lasting system. If the system is built for the current requirements, the infrastructure might be underestimated and will not fulfill all needs in the future. If the system is built with foresight, it might be overestimated and costs too much. A solution to this problem is to build an infrastructure in a flexible way, which can be adapted easily to the futures needs.

To cope with this challenging task the Real Option methodology can be used. For this methodology certain key parameters are defined, which have a major impact on the level of service of the infrastructure. The developments of these key parameters are then simulated. Based on these simulations the costs and benefits of several pre-defined designs are estimated and compared to each other, to select the optimal one.

An upturning trend is the technology of electrical vehicles (EVs). This upcoming of the EV technology leads to a higher number of EV users. From the infrastructural side of view, the main need of these electrical vehicle owners is to have an electrical charge facility for their car, where they park it. However, this upcoming of electrical vehicles could lead to various difficulties for a building manager, since it is fraught with uncertainties. These uncertainties subsist because of the long life span of infrastructures. It is highly unknown, what the requirements and circumstances in the future are. It is uncertain, how high the need of electrical charge facilities will be in the coming decades and which factors are going to affect its development. A flexible design of a facility would counteract this uncertainty with its adaptability towards different future scenarios and their corresponding probability of occurrence.

Therefore, this project work conducts the question of the determination of the optimal implementation design of a parking garage regarding the uncertain future need of electrical charge facilities due to the upcoming of electrical vehicles. Different flexible and non-flexible designs are examined to determine the optimal design for the parking garage.

2 Background

The aim of the Real Option methodology is to make adequate decisions regarding the initial implementation of an infrastructure depending on possible future scenarios and their corresponding probability. However, the standard procedure for the design of engineering systems is not based on the Real Option methodology. More often a facility is designed for determined factors like the “most likely” or “average” scenario, which leads to a non-optimal initial implementation. But in fact, our facilities are affected by a huge number of uncertainties, such as technological changes, economic and financial conditions, or political issues (Martani 2018). Just to name some of them. The Real Options methodology takes these uncertainties into account for the determination of the optimal initial design for a facility.

The Real Option methodology can be applied for various problems. Table 1 shows a selection of previous studies on the application of a flexible design for an infrastructure.

Table 1: Previous studies on flexible design for an infrastructure

Authors (year)	**Modelled variable**	**Uncertainties**	**Topic**
de Neufvill, Scholtes and Wang (2006)	Parking spot benefits	Parking demand	Flexible building design to increase parking capacity
Esders, Della Morte and Adey (2015)	Benefits of barrack configuration	Number and share of female soldiers	Flexibility in barracks facility, renewal projects
Schachter, Mancarella, Moriarty and Shaw (2016)	Electricity distribution network life cycle costs	Energy demand	Capacity extension of smart distribution networks
Esders, Adey und Lethanh (2016)	Building life-cycle costs	Fuel price	Facade refurbishment
Martani, Cattarinussi und Adey (2017)	Building life-cycle costs	Building demand	Ceiling height by use categories in real estate
Elvarsson (2018)	Net benefit	Parking demand	Optimal implementation of a parking garage

It can be seen, that the Real Option methodology can be widely applied for different problems, which are affected by huge uncertainties. It considers these uncertainties for the determination of the optimal design, which in turn generates the lowest costs, respectively the highest benefit over the examined period. As it is listed in Table 1, there has been already an analysis about the determination of the optimal implementation of a parking garage accounting the future mobility uncertainty and the associated decrease in parking space demand due to the upcoming of automated vehicles (Elvarsson 2018). Therefore, this study examines the possible effect only of the automated vehicles on the parking situation. As seen before, there is, however, another trend, which could be even more popular than the automated vehicles and has a substantial effect on the future parking situation as well. Meant is the future upcoming of electrical vehicles. Therefore for this master project work, the Real Option methodology is used to determine the optimal initial implementation for a parking garage considering the uncertainty on the market penetration of electrical vehicles.

3 Methodology

To answer the question of this master project work a defined methodology is used. The methodology is mainly taken over from The Real Option methodology from Martani (2018), which is slightly adapted to completely cover all issues associated with the case study. In Table 2 the steps 1 to 9 of the methodology is described.

Table 2: Methodology, step 1 to 9

Step	Description
1	**Definition of system boundaries and assumptions**
	At a first step, the scope of the study has to be defined. Therefore, the system boundaries have to be set, and all assumptions need to be listed.
2	**Assessment of LOS**
	For the assessment of LOS the expected function of the infrastructure during its life span needs to be defined. The demanded LOS is highly dependent on the requirements the infrastructure needs to fulfill. A good way to assess the desired LOS of an infrastructure is to think of its stakeholders and their needs.
3	**Analysis of key parameters**
	Values, which have a high probability to have an impact on the infrastructure to have an adequate LOS are called key parameters. The analysis of these key parameters consists of the identification of these parameters, the analysis of the past evolution, the evaluation of change in trends and the modeling of the future development of them.
4	**Identification of possible ways to implement and change infrastructure**
	To define the implementation design in the next step, all possible and reasonable ways to implement and change the infrastructure should be worked out and listed.
5	**Definition of designs for t = 0**
	Out of the possible ways to implement and change the facility, worked out in the last step, several implementation designs are put together and defined. For flexible implementation designs the thresholds to trigger an intervention is defined as well.

6	**Establishment of static model**
	With the establishment of the static model, the desired LOS is tried to be expressed with a function including the key parameters. In the static model the key parameters are assumed to be known.
7	**Establishment of dynamic model**
	The dynamic model is based on the static model defined in the previous step. The static model is therefore complemented with the varying key parameters over time.
8	**Estimation of costs for each design**
	To estimate the benefit of each design, the costs of each design needs to be defined. To ensure the comparability of the designs, the costs should have the same basis.
9	**Estimation of benefits of each design**
	With the dynamic model and the estimated costs, the benefit of each design can be calculated. The mean and the standard deviation of each design indicates, how beneficial the design is and how much the benefit varies.

4 Case study

The examined building complex lays in Bussigny VD in Switzerland. It consists of several different building types, including residential, office, retail, industrial and parking. Within this master project work only the parking garage is considered and all influences from the adjoining buildings are neglected. The rent for a parking space in the parking garage is 1’452 CHF per year (Elvarsson 2018).

The parking garage is made up of four levels and 463 parking spaces, whereas a level contains 115 or 116 parking spaces. All levels combined cover an area of 14’000 m^2 (Elvarsson 2018). A cross section of the parking garage can be seen in Figure 1.

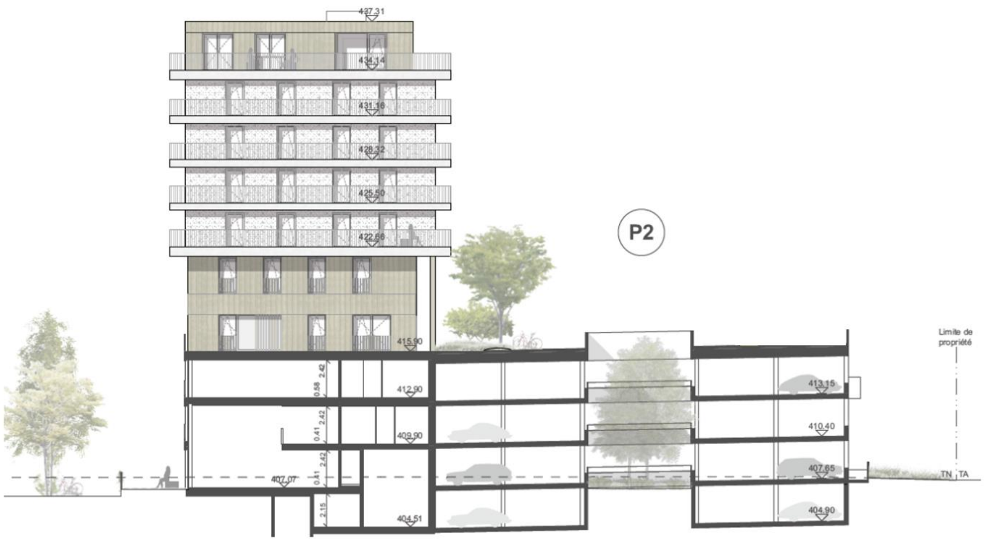

Figure 1: Cross section of the examined parking garage in Bussigny VD

5 Application

5.1 Definition of system boundaries and assumptions

For the implementation of the Real Option methodology following assumptions and simplifications are made:

- All influences from the adjoining buildings of the building complex are neglected.
- Each level of the parking garage is equal and consists of 115 parking spaces. Therefore, the parking garage contains 460 parking spaces in total.
- For the implementation of each design, there is no need to distinguish between the different levels of the parking garage.
- Most of the data from the federal department of energy, regarding the EV development in Switzerland, is done on a yearly basis. The latest data is from the year 2017. Therefore the year 2017 serves as the initial year of this study.
- The analysis of the flexibility of the parking garage is made on a period of 60 years, therefore the years from 2017 to 2077 are examined.
- There is no distinction between a hybrid and an electrical vehicle. They both need to have an electrical charge facility in order to charge their batteries.
- The needed electricity to charge the EV is paid by the user individually and is not considered.
- The demand in vehicles is steady. Therefore, the demand in parking spaces without an electrical charge facility, called traditional parking space and the demand of parking spaces with an electrical charge facility, called electrical parking spaces, always adds up to 100%.
- The rent for an electrical parking space is higher, than for a traditional parking space.

5.2 Assessment of LOS

The two main stakeholders of the parking garage are the owner and the users. Some needs of the owner could be to maximize the owner’s net benefit, to minimize unused parking spaces or to maximize the satisfaction of the user. On the other hand, the needs of the user could be to minimize the users’ costs or that every user has a parking space.

For this master project work only the needs of the owner are considered. It is comprehensible the most relevant need of the owner is to maximize the owner's benefit. Therefore, the required level of service is to maximize the benefit of the owner including initial and operational stages.

The benefit of the owner is depending on following factors; how many parking spaces of the parking garage are rented, how much the rent and the maintenance of a parking space cost, and how much the implementation of possible electrical charge facilities costs. It can be seen, that the rent can be defined directly by the owner. Furthermore, the maintenance costs of the parking garage are not affected by any uncertainties regarding the upcoming trend of EVs. However, the number of rented parking spaces and the implementation cost are depending on the uncertain development of the EV technology. The number of rented parking spaces are depending on the market share of EVs, because the higher the market share, the higher is the demand of electrical charge facilities. If too less electrical charge facilities are implemented, there might be some EV users, which refuse to stay at the parking garage. The same thoughts can be applied for the non-EV users. If too many electrical charge facilities are implemented, there might be too less normal parking spaces and some non-EV users will refuse to rent a parking space at the parking garage. Additionally, the implementation costs for the electrical charge facilities are depending as well on the number of implemented charging facilities and on the costs of such a charging facility.

Therefore, the benefit of the owner is depending on the number of implemented charging facilities, which in turn should be depending on the market share development of EVs. Furthermore, it is comprehensible, that the user behavior can't be determined easily. It is unknown, how a user will react to the new market situation. Because of that, the user behavior and its impact on the benefit should be examined as well. This means, that for the optimal design of the parking garage, it needs to be determined, how much electrical charge facilities should be implemented to generate the highest benefit for the owner.

5.3 Analysis of key parameters

5.3.1 Identification of key parameters

As seen in the previous section, there are several factors, which have an influence on the level of service of the parking garage. The three considered key parameters are the market share of EVs, the development of the costs of the charging stations for the EVs, and the behavior of the users regarding the change in the market situation.

5.3.2 Market share of EVs

The market share of the EVs has a direct impact on the required number of electrical charge facilities of the parking garage. If the market share is high, there are more EV owners, which leads to a higher demand of electrical parking spaces. And the required number of electrical parking spaces has an influence on the optimal design.

5.3.2.1 Development until now

The upcoming of EVs started roughly in the year 2000, where 754 EVs were registered in Switzerland. With a total number of 3’545’247 motor vehicles the market share of EVs lays at that time at 0.02 %. Along with the development of the EV technology during the last 17 years, the number of EVs rose up to 14’539, which resembles a market share of 0.32% (BFS 2010). The development of the market share of EVs in percent is shown in Figure 2.

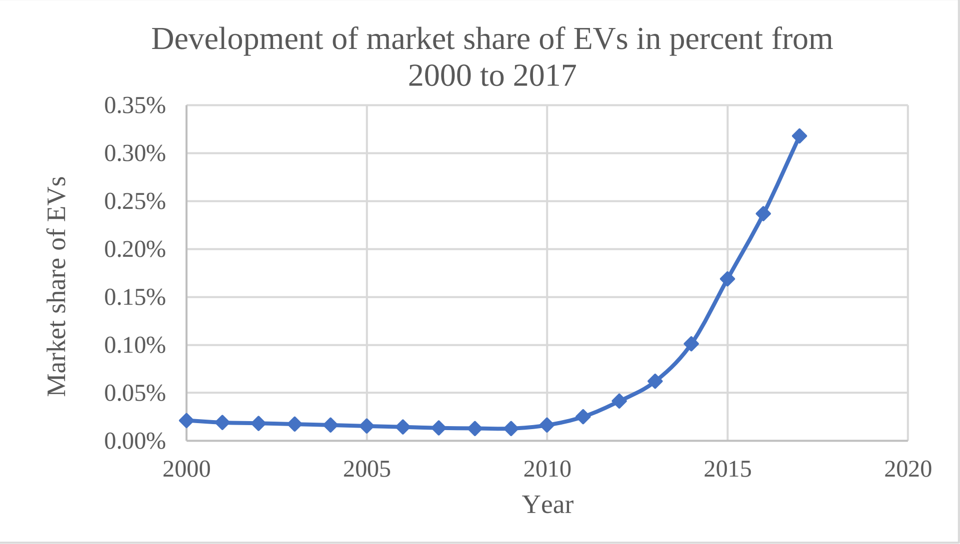

Figure 2: Development of market share of EVs in percent from 2000 to 2017

5.3.2.2 Change in trends

In Figure 2 it can be seen, that there is a change in trends in the market share of EVs in year 2010. The market share rose within 7 years from 0.02 % to 0.32 %, which resembles a rise of 0.05 % each year. This leads to the estimate that, the propagation of EVs is now about to start. And since the technology of EVs is continuingly developing and improving, it can be assumed, that the EV technology is at a point, where it is sellable and affordable for a wide number of users. Regarding the Mobilitätsmonitor 2018, 72 % of those polled stated, that they considering buying next a vehicle with alternative drive system (Bieri, et al. 2018). This indicates an even higher and faster ascending of the market share of EV in the future.

5.3.2.3 *Expected Development*

To estimate the expected development of the market share, different estimations on the development of the market share of EVs are gathered. This data should indicate a scale for the future development of the key parameter and is shown in Figure 3 below.

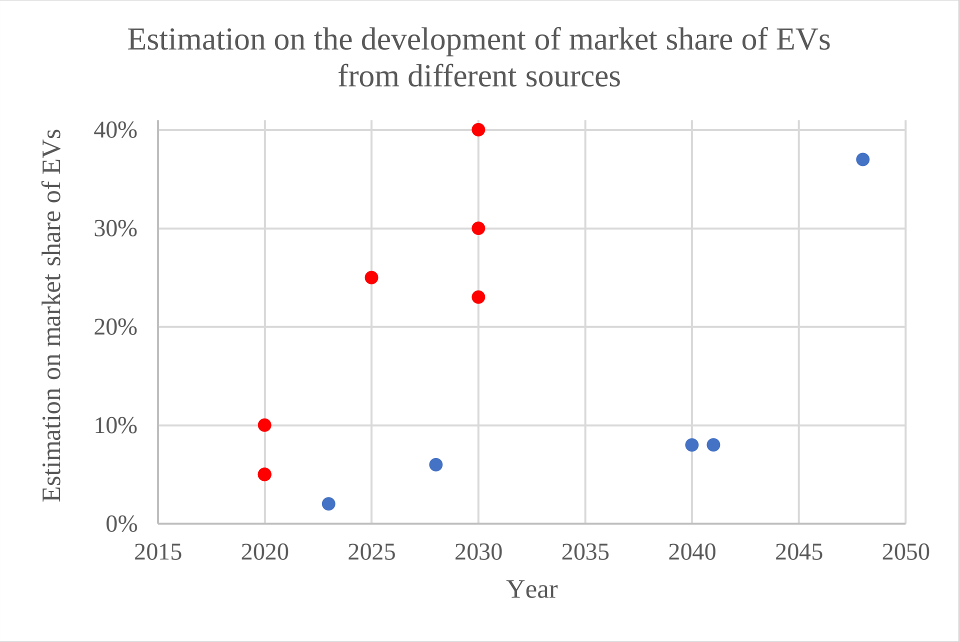

Figure 3: Estimation on the development of market share of EVs from different sources

It can be seen in Figure 3, that the market share of EV has a huge uncertainty within. But based on the past development and the change in trends it is assumed, that the EV market share is more likely to pick up, rather than staying low. Therefore only the red marked data points will be included in the modeling of the uncertainty.

Another considered aspect is the form of the curve, which resembles development of the market share. Considering the change in trends and Figure 2, which indicate a starting boom, the market share is assumed to rise rapidly at the beginning. However, it is comprehensible, that this initial interest in the EV technology and the associated rising of the market share will be flattening and even decreases again with time. The lower boundary of the development of the market share is assumed to be steadily 0 %, since the initial market share is nearly 0 %, there isn't any possibility to be lower than that. The upper boundary should have the same form as the development of the market share discussed above. The only difference is, that if the market share reaches 100 %, the curve remains steady at 100 % for the following years. To have an idea in which year the upper boundary will reach 100 %, a regression analysis with the selected data (red marked points) is done.

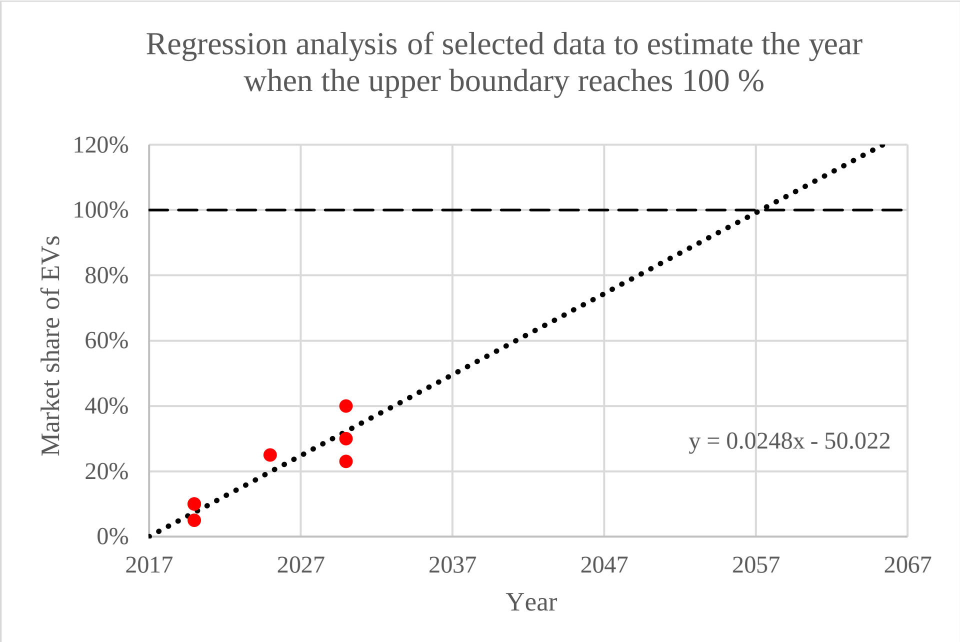

Figure 4: Regression analysis of selected data to estimate the year when the upper boundary reaches 100 %

Figure 4 shows the selected data and the regression line with the function $y = 0.0248x - 50.022$. The pointed line resembles the regression line. The dashed line indicates the market share of 100 %. The linear regression analysis is carried out to determine, in which year a market share of 100 % is reached, with the condition that the rate of growth stays the same for the entire time. With this, the expected development is overestimated. Therefore, it is assumed, that the regression line indicates the maximal market share, which can be seen as an upper boundary. The intercept with the y-axis is chosen to be 0.32 %, which resembles the actual market share in 2017, as determined in subsubsection 5.3.2.1. Figure 4 shows, that a market share of 100 % is reached at around year 2057. Therefore, it is assumed, that the upper boundary reaches 100 % of market share of EVs after 40 years, in 2057.

Furthermore, based on the analyses before it is assumed, that the expected market share is more likely to be higher than the midpoint of possible range. However, this likeliness is not sure to subsists throughout the whole 60-year period. Therefore the modeling of the future development is done for two independent periods; for the first 40 years until the upper boundary reaches 100%, and for the last 20 years. Following the modeling of the future development for both periods are explained.

Within the first 40 years the expected value is considered to be more likely, so that the expected market share lays above the midpoint of possible range of market shares. This is taken into account with the modeling of the probability distribution of these years. The probability distributions are modelled to be skew. The modelled shape of the probability distributions for the first 40 years can be seen in Figure 5.

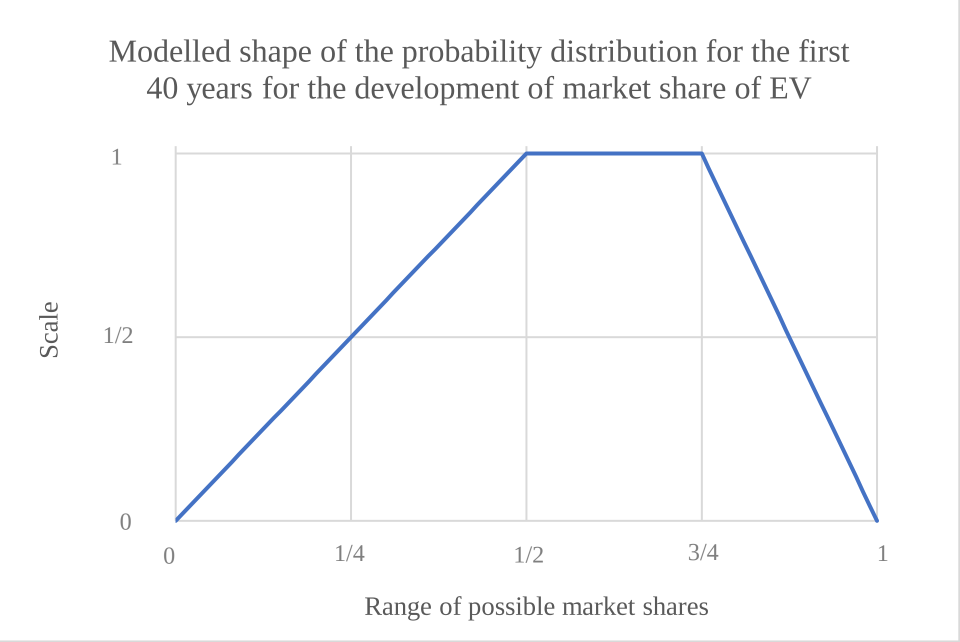

Figure 5: Modelled shape of the probability distribution for the first 40 years for the development of the market share of EV

The x-axis indicates the difference between lower and upper boundary of the examined year, which resembles the range of possible market shares of that year. The y-axis indicates a scale. The scale is used, so that the area under the blue line adds up to 1, or likewise 100 %. The increasing line reaches the scale 1 within one half of the range of possible market shares. The decreasing line gets from 1 to 0 within one fourth of the range and is steeper than the increasing line. In between the scale has a value of 1. A regression analysis is done, to determine a function, which describes the desired curve. In this case a 3rd grade polynomial function is chosen. The modelling of the probability distribution is done for every year from 2018 until 2057. For year 2017 there is no need to model a probability distribution since the market share is known to be 0.32 %. As an example, Figure 6 and Figure 7 show the probability distributions of the year 2018, respectively year 2057. It can be seen, that the shapes of the distributions differ not much, and are quite similar to the shape modelled in Figure 5. Furthermore does the skewness of the distributions indicate as intended, that the expected value lays slightly above the midpoint of the range of market shares. But there is certainly a difference in the scale. The probability distribution for year 2018 has a smaller range of possible market shares, which leads to a higher probability for the individual market shares. The probability distribution for the year 2057 has a larger range of possible market shares, which leads to a quite flat curve for the distribution and low probability for the individual market shares.

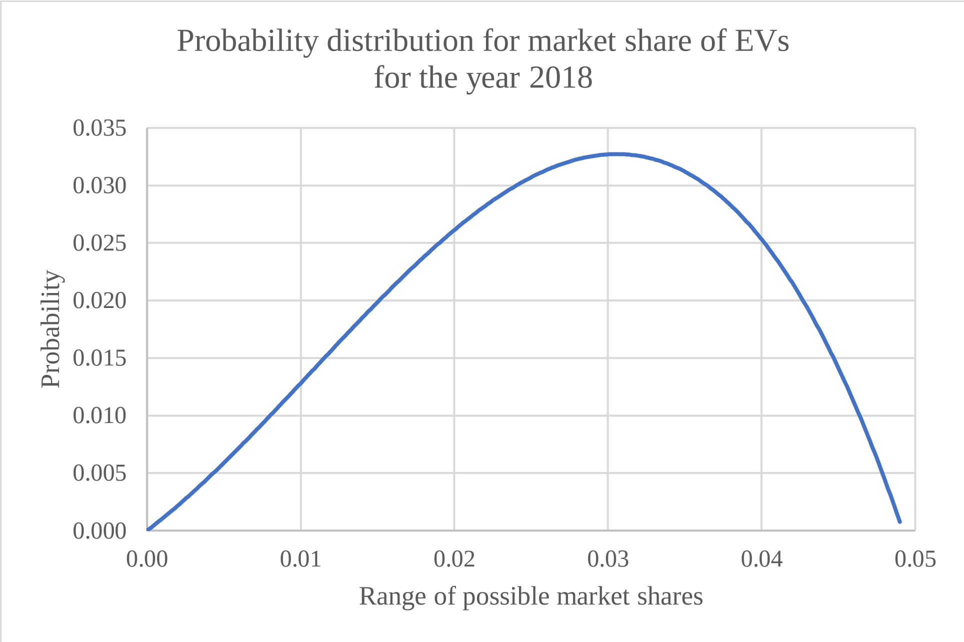

Figure 6: Probability distribution for market share of EVs for the year 2018

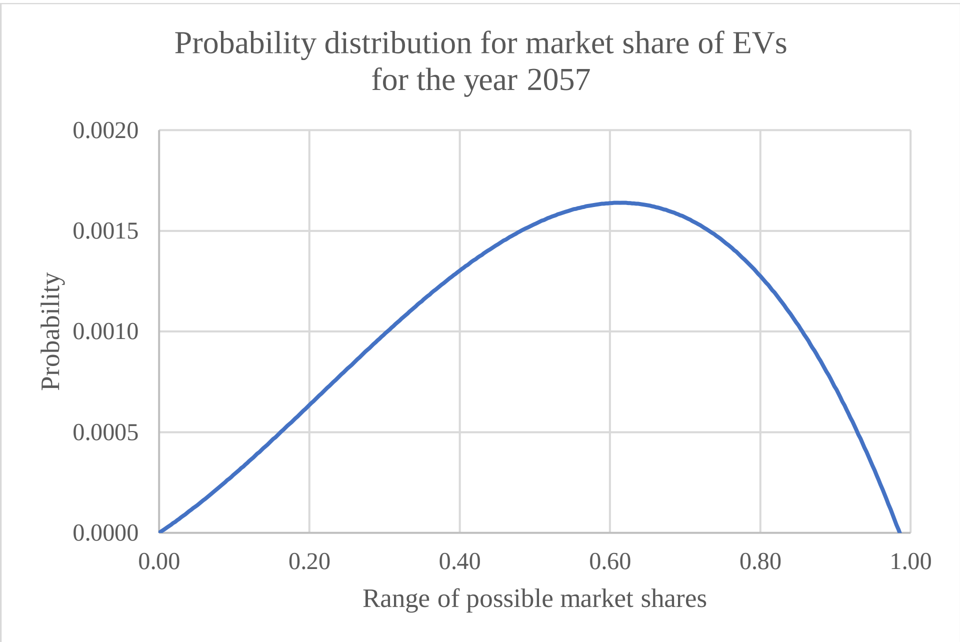

Figure 7: Probability distribution for market share of EVs for the year 2057

The flattening of the probability distribution with progressing time can be seen in Figure 8. Figure 8 shows the probability distributions from year 2018 to year 2028. With ongoing years the range of possible market shares gets bigger. And since the area under the curve always needs to be equal to 1, the probability for each market share gets lower, which means, the curves flatten out. It should be mentioned, that the flattening of the probability distributions happens with the same rate as the rising of the upper boundary of the market share of EVs, since these two values are linked.

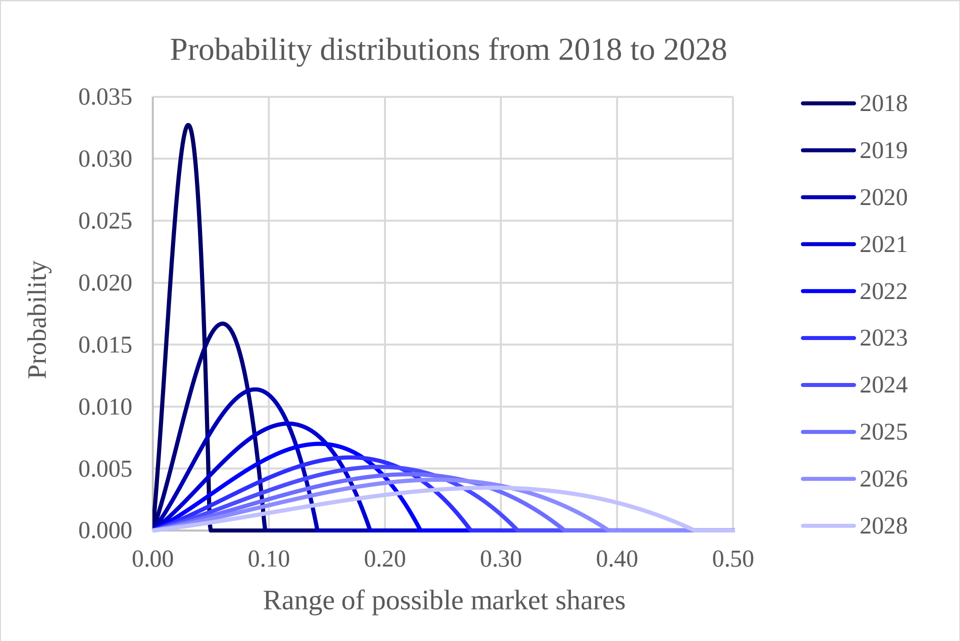

Figure 8: Probability distributions from 2018 to 2028

The other part to look at are the last 20 years of the examined 60-year-period. Since this period lays so far in the future, it is uncertain if the market share is still likely to be higher than the midpoint of range. Therefore, the expected market share is modelled to decrease again. This decreasing in market share is modelled with the shifting of the mode and expected value of the probability distributions towards the midpoint of range, which is 0.5. The shifting is done by changing the slope of the increasing line seen in Figure 5. The shapes of the probability distributions for the years 2057, 2062, 2067, 2072 and 2077 are shown in Figure 9 as an example.

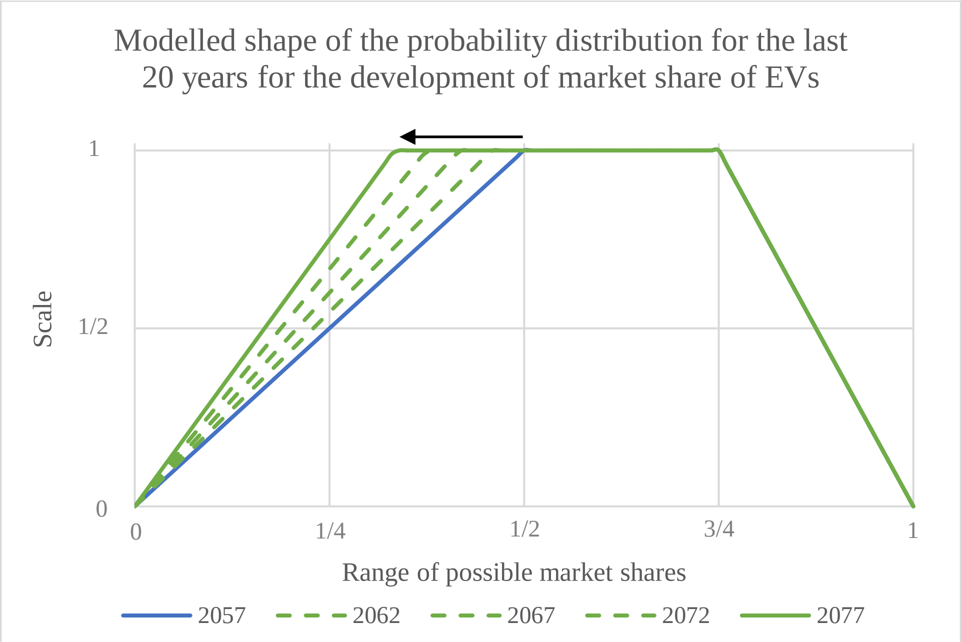

Figure 9: Modelled shape of the probability distribution for the last 20 years for the development of market share of EVs

The blue line indicates the increasing line for the year 2057. It is the same as for the other modelled shape in Figure 5 for the first 40 years. The green dashed lines resemble the change of slope and the associated change of the shape with ongoing years. The arrow indicated the direction of the shifting. The solid green line shows the shape of the probability distribution for the year 2077. The change in the slopes of the increasing lines (blue, dashed green and solid green) throughout the years is linear, so that the blue line reaches the scale 1 within one half of the possible range of market share and the solid green line reaches scale 1 within one third of the possible range of market share. This change in slope throughout the last 20 years leads to the desired shifting of the mode and the expected value to the midpoint of range. In Figure 10 and Figure 11 the probability distributions of the year 2057, respectively year 2077, can be seen. Since in the last 20 years the range of possible market shares stays the same, namely 100%, the scale of the probability distributions is quite similar. The main difference however lays in the shape. The probability distribution for the year 2057 is the same as in Figure 7. In Figure 11 can be seen, that the mode of the probability distribution of year 2077 shifts to the midpoint of range, leading to a decrease of the expected value over the last 20 years.

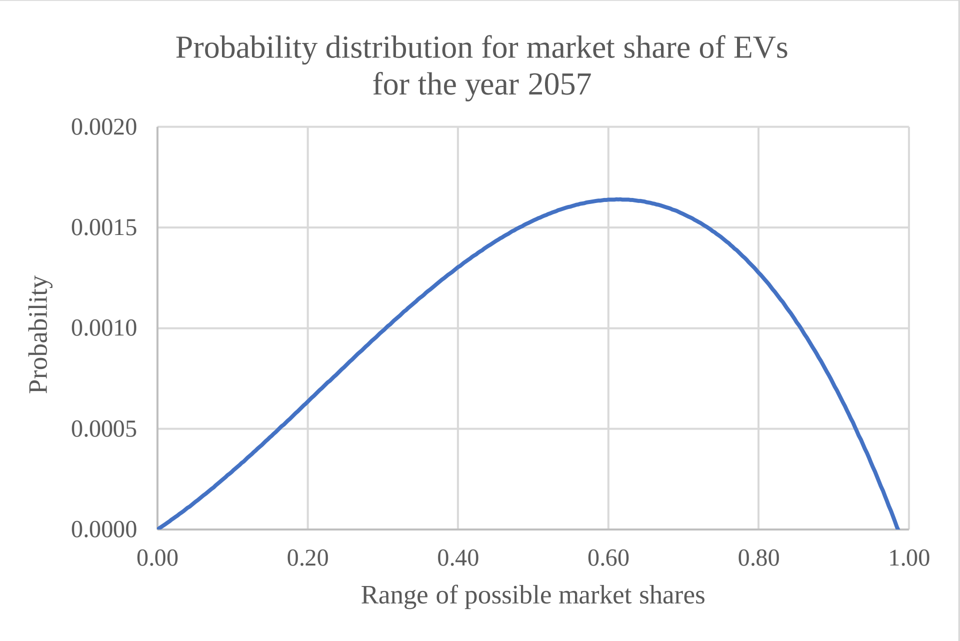

Figure 10: Probability distribution for market shares of EVs for the year 2057

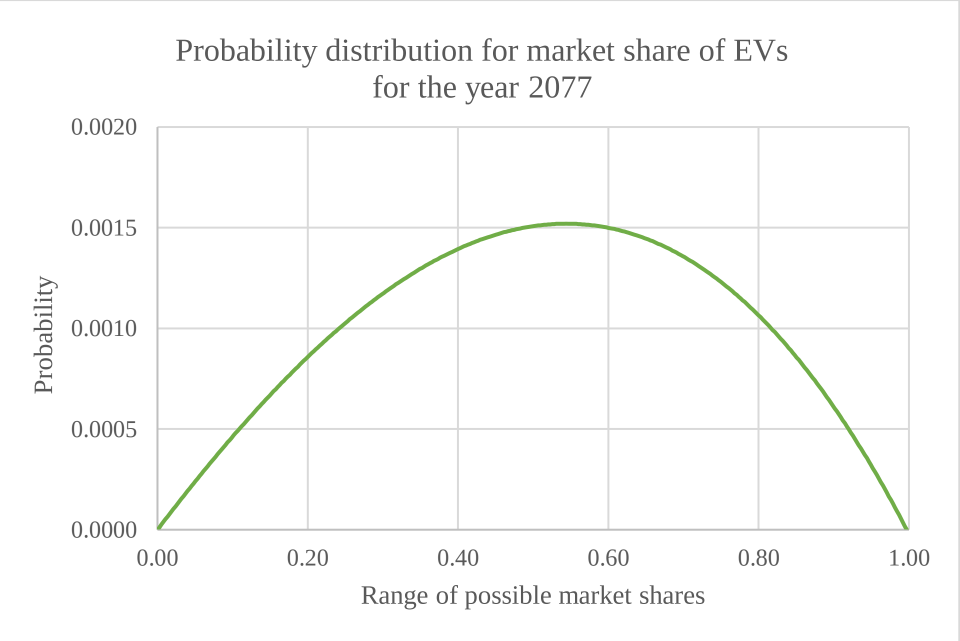

Figure 11: Probability distribution for market shares of EVs for the year 2077

In Figure 12 the probability distribution of the years 2057, 2062, 2067, 2072 and 2077 are shown as an example. The change in shape and the shifting of the mode towards the midpoint of range over the last 20 years can be seen. Furthermore, it can be seen, that the skewness of the curves gets smaller.

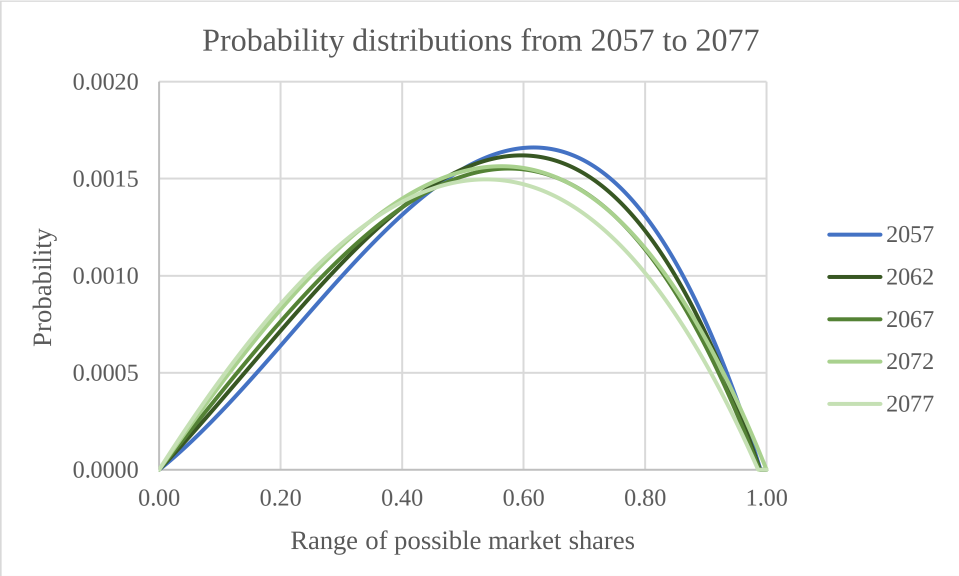

Figure 12: Probability distributions from 2057 to 2077

With the modelling of the boundaries and the probability distributions for all 60 examined years, the expected development of market share can be calculated and possible scenarios regarding the development of the market share can be generated.

Figure 13 shows the modelled development of the market share of EVs. The upper and lower boundary are drawn in black. The expected market share is drawn in yellow. It can be seen, that the expected market share follows fairly the considered red data points. Furthermore, it is shown, that the expected market share rises fast at the beginning and flattens out with ongoing years. Actually, the expected market share slightly decreases after the year 2057.

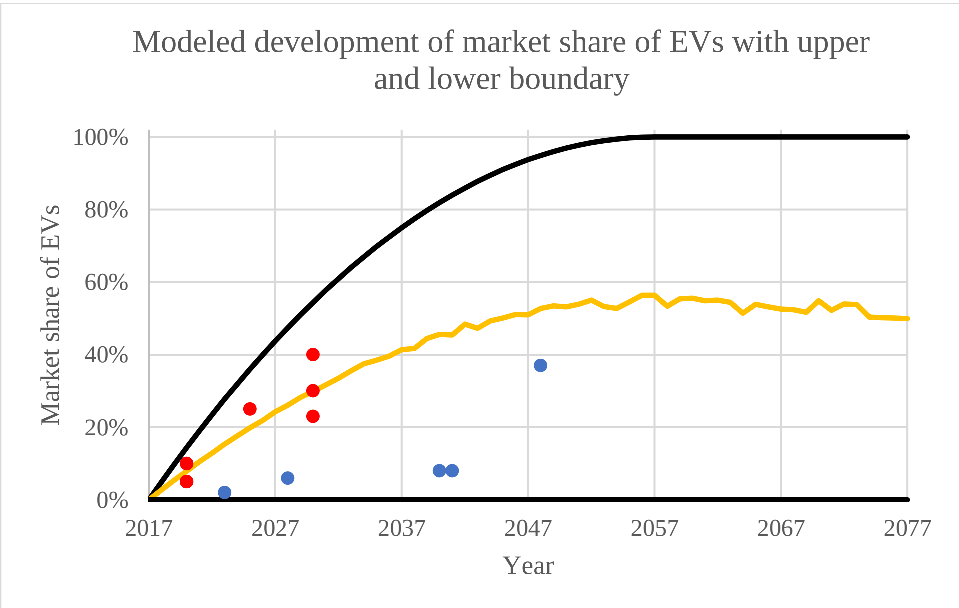

Figure 13: Modeled development of market share of EVs with upper and lower boundary

The modeling of possible scenarios regarding the development of the market share is done by selecting a random number for the development of the market share r_{ms}, which resembles the uncertainty, different trajectories for the market share development. Some examples for different trajectories can be seen in Figure 14. It shows, that if the random number is quite low (r_{ms} = 0.05), the EV technology is not taking up, and the market share of EVs stays low. If the random number is high (r_{ms} = 0.95), the scenario displays a booming of the EV technology and the market share rises rapidly.

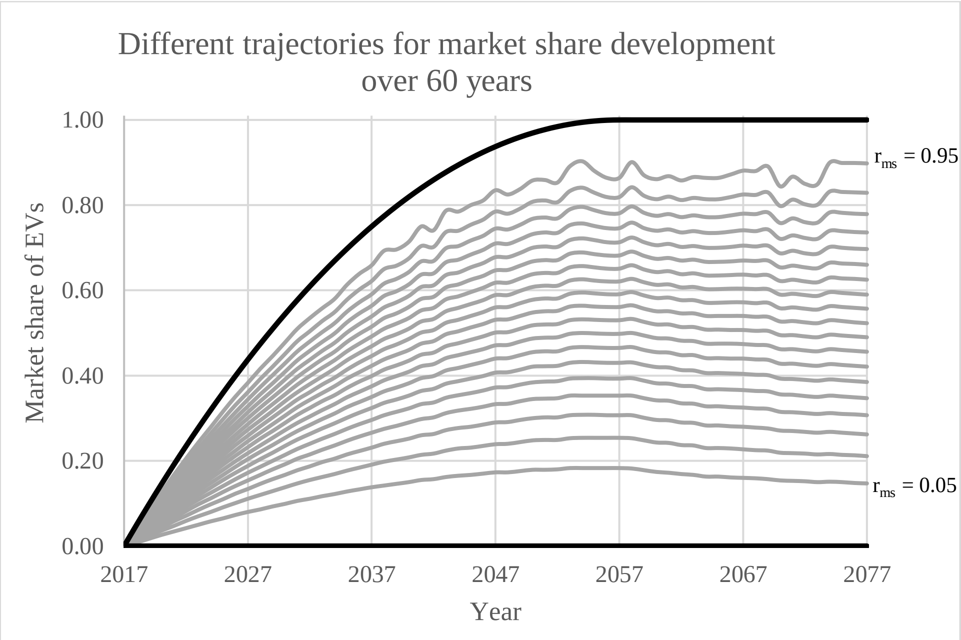

Figure 14: Different trajectories for market share development over 60 years

5.3.3 Costs of charging stations for EVs

The second key parameter is the development of the costs of the charging station of the EVs. As it can be seen later in subsection 5.8.1, the costs of the charging station represents a substantial part of the implementation costs. Then again, the implementation costs have a huge impact on the costs and benefit of a design. Therefore, the costs of the charging stations for the EVs are seen as a key parameter and included into the modelling of the uncertainties.

Since the EV technology has just recently began to develop, there isn’t any useful data available regarding the past development of the costs of the charging stations of EVs. Therefore just an analysis on the future development is made.

5.3.3.1 Expected Development

To have an idea how the costs of the charging stations would develop in future, two available cost prognoses of comparable technologies are analyzed as references. The reference technologies are the technology of photovoltaic and geothermic systems, e.g. heat pumps. Photovoltaic is a quite new technology as well, which experienced a similar amount of interest at its early stages. The technology of heat pumps has nearly the same interest. According to the swiss federal statistical office, the numbers of newly implemented heat pumps are growing since 2000.In 2017 nearly 20 % of the residential buildings have a heat pump as heating system (BFS 2018). This leads to the assumption, that the costs of charging stations for EVs will develop analogously to the costs of the two reference technologies.

For each reference technology different estimates on the cost development are gathered and averaged for the same year. A regression analysis is done. In this case a 2nd grad polynomial function is used to describe the cost development of both technologies. In Figure 15 and in Figure 16 the averaged cost estimates and cost development of the photovoltaic, respectively the heat pump technology are shown. The x-axis resembles the years, after the technology starts to establish. The y-axis resembles the percentage of the initial price. Therefore both curves start at 100 % and decrease with progressing time, since the costs sink with further development of the technology. The function to describe the cost development of the charging stations of the EVs is the mean of both gained regression functions. Therefore, the equivalent coefficients are averaged. This leads to the function $y = 0.00045x^2 - 0.03215x + 1$ for the expected cost development of the charging stations.

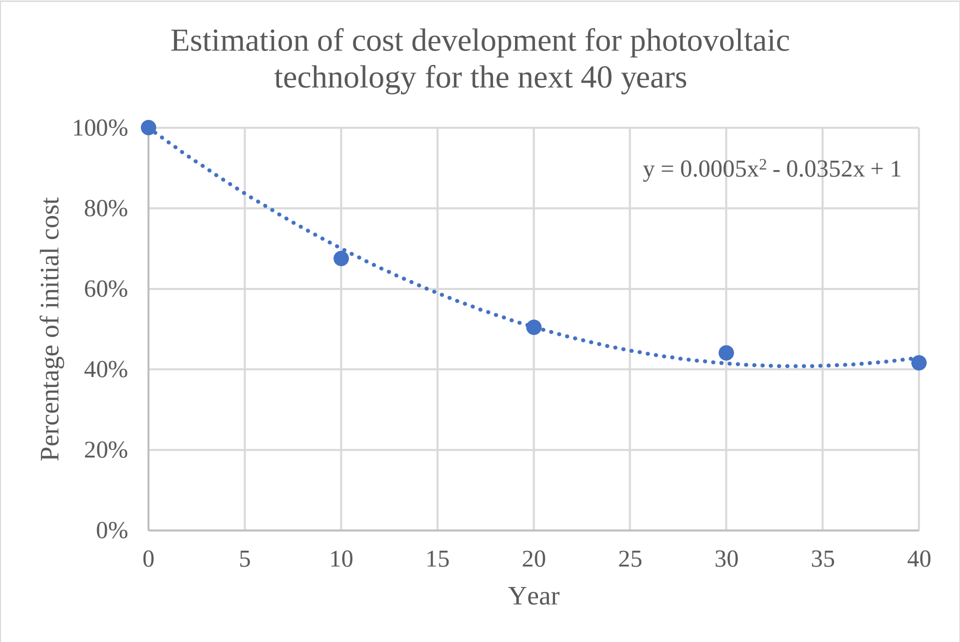

Figure 15: Estimation of cost development for photovoltaic technology for the next 40 years

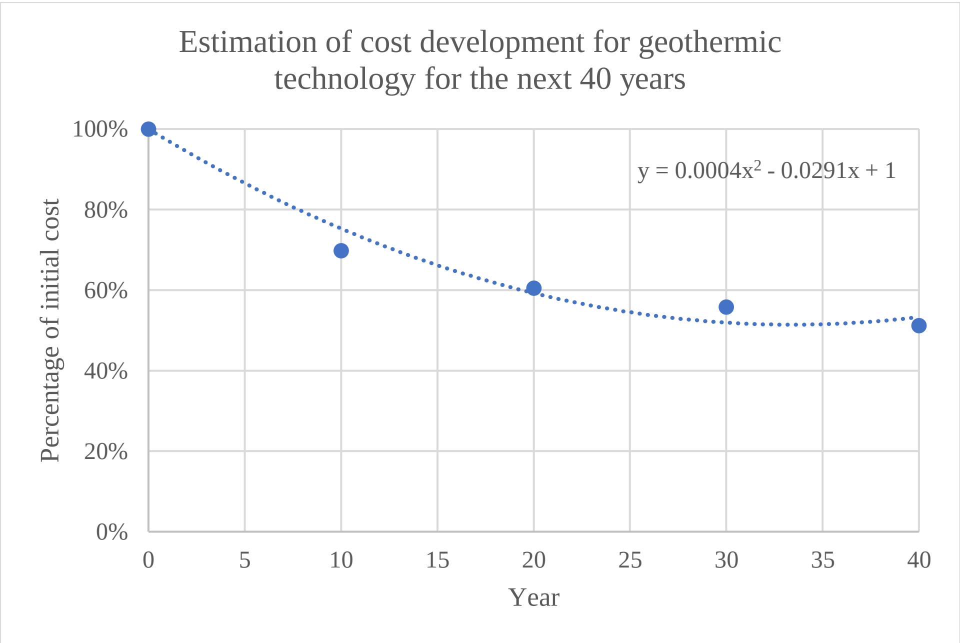

Figure 16: Estimation of cost development for geothermic technology for the next 40 years

In Figure 15 and Figure 16 can be seen, that both reference technologies decrease in costs within 30 years to a minimum of 40 %, respectively 50 %, which is relatively low. To not overestimate the decreasing of the costs of the charging stations and therefore not underestimate their impact on the determining of the optimal design, the gained function for the expected cost development is seen as a lower boundary.

The scenario, where no decreasing in costs is happening, is seen as upper boundary. Therefore, the price will stay constant at its initial value. The probability distribution for the costs of a charging station is modelled as a normal distribution for each year. The development of the costs of a charging station can be seen in Figure 17. The initial costs of the implementation of a charging station is estimated to be 1’200 CHF, as seen in subsection 5.8.1.

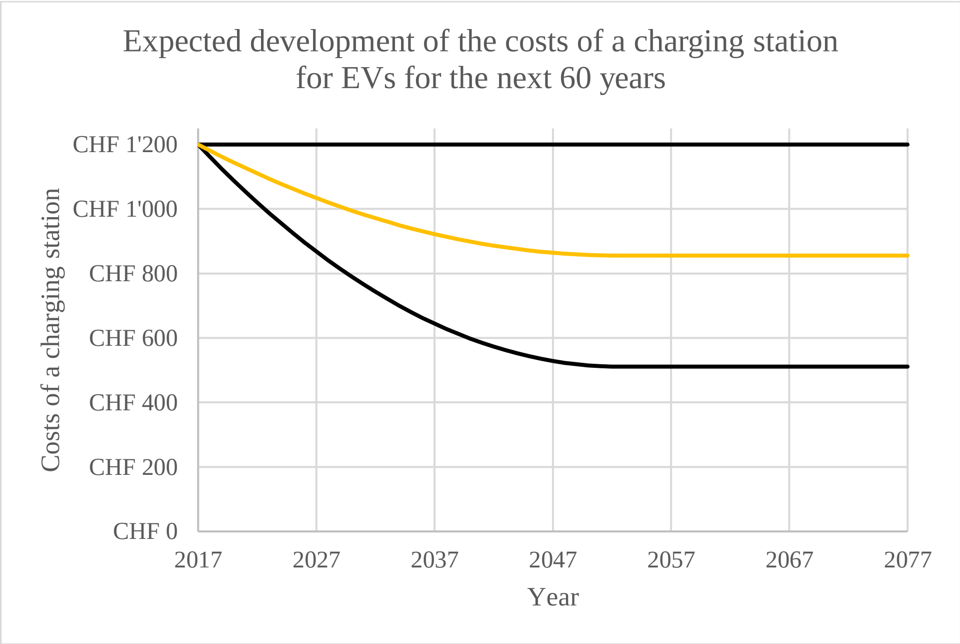

Figure 17: Expected development of the costs of a charging station for EVs for the next 60 years

Again, the two boundaries are drawn in black. The yellow line resembles the expected value of the costs of a charging station. The lower boundary, as well as the expected value, reaches its minimum in year 2052, after 35 years. It is assumed, that after this point, the costs will not raise again and will stay the same for the rest of the examined time period of 60 years.

Another aspect, which needs to be considered, is the linkage between the development of the costs of a charging station and the development of the market share of EVs. It is assumed, that if the market share of EVs is picking up the technology of the charging station will be further developed, which leads to a drop in price. On the other hand, there will be no investment in the further development of the technology and the costs of the charging station will stay high if the market share development of EVs does not pick up. This dependency is taken into account with the defining of the random number of the costs for a charging station r_c as a function of the random number of the market share r_{ms}. The function is chosen as $r_c = 1 - r_{ms}$. Therefore a high random number for r_{ms} leads to a high market share and a low random number for r_c. And a low random number for r_c resembles again a high decreasing in costs for a charging station.

Analogously as for the market share, different trajectories can be generated for different random numbers. Some trajectories are shown in Figure 18 as an example. It can be seen; a low random number for r_{ms} resembles just small investment in the research of the technology and therefore a smaller decrease in costs for a charging station. Vice-versa does a high random number for r_{ms} indicate a substantial development, which leads to a higher decrease of costs.

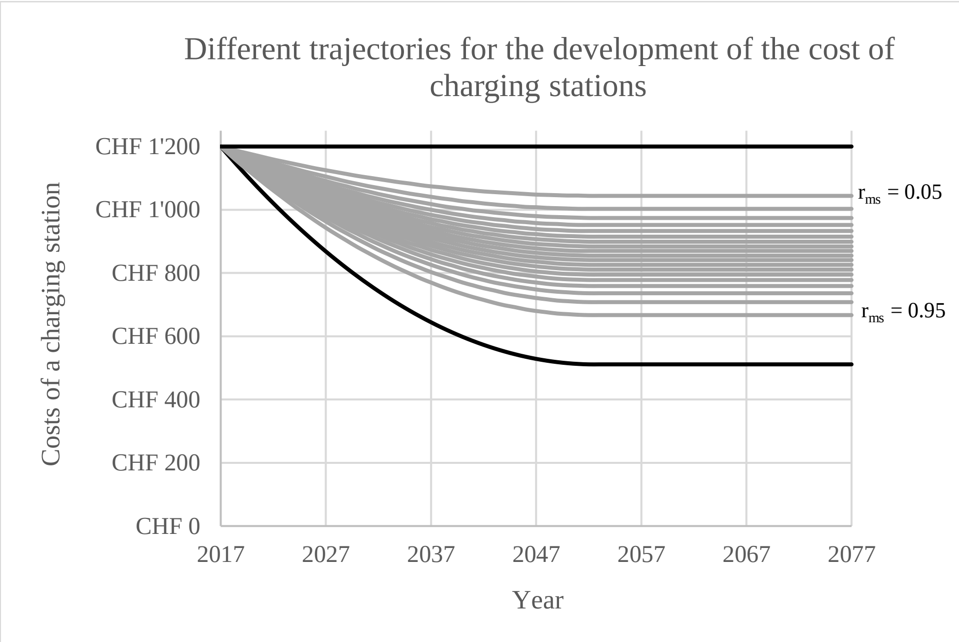

Figure 18: Different trajectories for cost development of a charging station over 60 years

5.3.4 Behavior of users regarding a change in the market situation

The third key parameter is the behavior of the users. It is unknown, how the users react to a change in the market situation and to a possible insufficient supply of parking spaces. There is the possibility, that unsupplied users will not park in the parking garage, which leads to a decrease in rented parking spaces. And this again leads to a decrease in benefit for the owner. The percentage of unsupplied users, which are still willing to park at the parking garage even though their needs are not fulfilled is from now on referred to as “acceptance”. 0 % acceptance indicate, that none of the unsupplied users will stay at the parking garage. 100 % acceptance indicate, that all unsupplied users will stay. There are two types of acceptances. The first one is the acceptance of a user with a normal or traditional vehicle, or from now on called traditional user, to rent a parking space with an implemented charging station for a higher rent. The second one is the acceptance of a user with an EV, from now called an EV user, to rent a parking space without an implemented charging station.

It is comprehensible, that the acceptance of a user is depending on the market share of EVs for both users. It is assumed, that if the market share is low, the acceptance of traditional users will be low as well, since the traditional users resemble the majority and they used to have a traditional parking space at lower costs. As the market share rises, the traditional users get familiar with the fact, that the number of traditional vehicles, and therefore the number of traditional parking spaces is decreasing, and that they can't demand to have a traditional parking space at lower costs. On the other hand the EV users are not used to have a parking space with an implemented charging station when the market share is low. But as soon as the market share rises and the EV technology is widely spread, the EV users get used to have a charging station for their EVs and will refuse to stay at a parking space without a charging facility. The modeling of the dependency of the acceptance of both users on the market share of EVs is shown in Figure 19, whereas the acceptance of the EV users is drawn in blue and the acceptance of the traditional users in green.

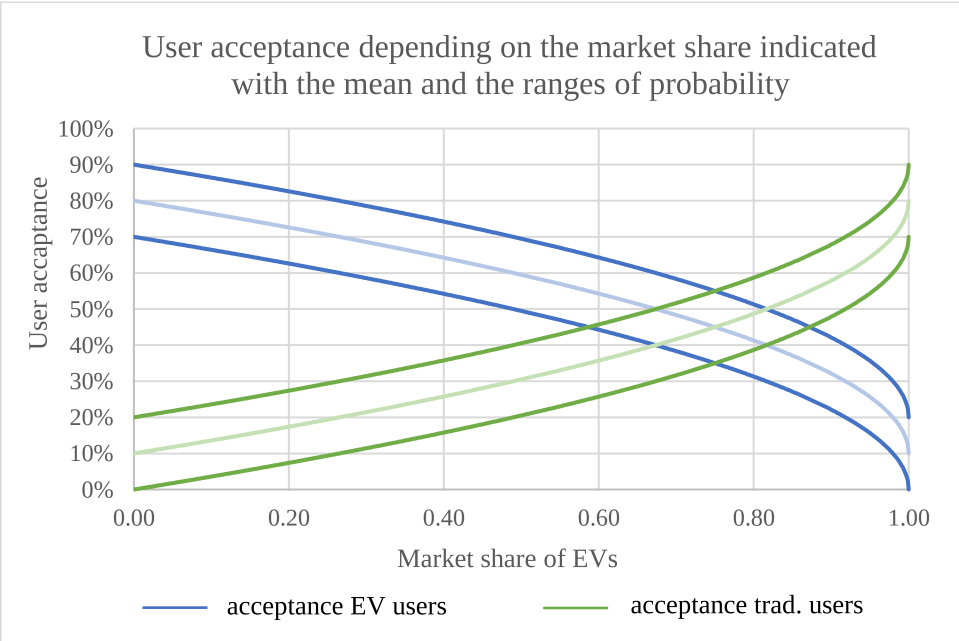

Figure 19: User acceptance depending on the market share of EVs

It is comprehensible, that both curves just indicate a trend for the acceptance depending on the market share and should not be seen as definite values. Instead a range is added to each curve, which can be seen in Figure 19 as well, whereas the middle line resembles the mean value, and the outer lines indicate the edges of the range. The probability of the different percentages of acceptance within this range is then modelled with a normal distribution, whereas the deviation from the midpoint is estimated to be 10 %.

The two family of curves are symmetrical and chosen to be root-functions to display the different rate in change of the acceptance depending on the market share. With the start of the rising in market share, the users get just slowly adapted to the EV technology and its spreading. But with the increasing in market share, the rate of change of the acceptance gets higher, since the users are more and more accommodated to the new market share of EVs. If a high market share is reached, the thinking of the users and their acceptance will change rapidly, since a point is reached, where it’s obvious, that the EV technology is now more common than the traditional vehicles.

The acceptance of the EV users decreases at a small rate with the rising of the market share. When a market share of nearly 90 % is reached, an unsupplied EV user conceives the lack of parking spaces with an electrical charge facility as unbearable and refuses to stay. On the other hand, the acceptance of an unsupplied traditional user changes slowly at a low market share, since they are used to have a traditional parking space without any restrictions. Only when the market share rises significantly, and the amount of traditional parking spaces therefore decreases substantially, an unsupplied traditional user will change its mind and does not demand a traditional parking space anymore. This will lead to a rapid growth in acceptance and therefore more unsupplied traditional users will stay at the parking garage, even though it costs more.

5.4 Identification of possible ways to implement and change facility

With the rising of the market share of EVs, the demand for parking spaces to accommodate these kind of vehicles, e.g. parking spaces with an implemented electrical charge facility, is rising equivalently. To supply this upcoming demand, the parking garage needs to be modified. The only reasonable modification is the additional implementation of charging stations for EVs. To implement the charging stations, it is assumed, that following steps need to be carried out:

1. Implementation of empty conduits
2. Drawing-in of electrical cables into empty conduits
3. Installation of a charging station at each parking space

The implementation of such high current devices is obviously not that simple as it is indicated in these 3 steps above. There would be analysis through an expert needed to plan and implement all the electrical systems. But due to simplification, just the 3 steps above are considered for the implementation of the charging facilities for EVs.

5.5 Definition of designs for t = 0

Based on the analysis in the previous section, different designs for the initial implementation of the parking garage are defined. There are two non-flexible and one flexible design. The two non-flexible designs are the two extremes for the initial implementation. One design is to implement no charging facilities at all and the other extreme would f implement all the electrical charge facilities right at the beginning. The third design is a flexible one, which can adapt according to the market share.

Furthermore, there are different ways to handle unsupplied users, which are explained in the following subsection 5.5.1. Afterwards the three already mentioned designs are described in more detail. At the end of this section a summary of all considered designs is done.

5.5.1 Policies

As describe in subsection 5.3.4, there are users, whose needs are not fulfilled due to a lack of either traditional or electrical parking spaces. The key parameter of acceptance is introduced to take into account the percentage of unsupplied user, which still are willing to park at the parking garage even though their needs are not accommodated. But it can be seen, that the number of users, which are not willing to park at the parking garage, could be fairly high for the non-flexible designs. This high number of outgoing users leads to a loss of potential income and is surely not the intention of the owner. Therefore, another way to cope with unsupplied users should be considered to counteract the possible outgoing of users. In the following. two possible policies from the owner are defined to handle the unsupplied users.

5.5.1.1 Policy 1

The first policy, Policy 1, is rather not a user-friendly one. The owner will not consider any possible complying towards the needs of the users and accept the fact, that some users will stop parking at the garage. The two possible situations with the corresponding consequence of the application of the policy are listed below:

Situation A: There are unsupplied traditional users.

The unsupplied traditional users need to rent an electrical parking space with the associated higher costs. This leads to the fact, that some users are not willing to pay for something they don’t need. The percentage of unsupplied traditional users, which are not willing to stay, is describe with the acceptance of traditional users, explained in subsection 5.3.4.

Situation B: There are unsupplied EV users.

The unsupplied EV users need to rent a traditional parking space, with the inconvenience of having no ability to charge their vehicle right at their parking space. This leads to the fact, that some users are not willing to accept that they need to charge their car elsewhere. The percentage of unsupplied EV users, which are not willing to stay, is described with the acceptance of EV users, explained in subsection 5.3.4.

5.5.1.2 Policy 2

The second policy, Policy 2, is a more complying one towards the users. The owner tries to accommodate the users as well as possible, to prevent their outgoing. Therefore all unsupplied traditional users are able to rent an electrical parking space at the same rent, as for a traditional parking space. The already implemented charging facility will be blocked. Therefore, the charging station can’t be used, and the parking space can be seen as a traditional one. However, the handling of the unsupplied electrical user will be the same as in Policy 1, since the problem of not having a charging facility at the parking space subsists. The two possible situations with the corresponding consequence of the application of the policy are listed below:

Situation A: There are unsupplied traditional users.

The unsupplied traditional users are able to rent an electrical parking space with a blocked charging station for the same rent as for a traditional parking space. This solution is seen to be equivalent to a traditional parking space for the traditional user. Therefore, it is assumed, that all unsupplied traditional users will stay at the parking garage, and there are no outgoing traditional users.

Situation B: There are unsupplied EV users.

Since there is no ability to accommodate the unsupplied EV users, the Situation B leads to the same outcome for both policies. The unsupplied EV users need to rent a traditional parking space, which causes some unsupplied EV users to stop parking at the parking garage. The percentage of unsupplied EV users, which are not willing to stay, is described with the acceptance of EV users, explained in subsection 5.3.4.

5.5.2 Traditional Design

The Traditional Design is a non-flexible design, which implements the parking garage on a traditional way. Therefore all parking spaces are traditional parking spaces, without any possibilities to change the infrastructure late. Since there are only traditional parking spaces, there is no way to accommodate EV users. And because there are just traditional parking spaces, only Situation B can occur. This means, that there is no need to distinct between the two defined policies. A percentage of the unsupplied EV users refuse to park at the parking garage.

5.5.3 Maximum Design

The Maximum Design is one of the non-flexible designs. It implements all the electrical charge facilities right at the initial implementation of the parking garage. Therefore, all parking spaces are electrical parking spaces, thus an additional change of the infrastructure is not needed. Since there are only electrical parking spaces, always Situation A occurs. Because of that, there is the possibility to apply both policies. This leads to a distinction between the implementation of the Maximum Design with either one of the two policies.

5.5.4 Flexible Design

The Flexible Design is a design, where the parking garage is built traditionally with the addition, that the empty conduits, needed for a later implementation of the electrical charge facilities, are brought in right at the beginning. With that, the drawing-in of the cables and installation of the charging station is possible at a later time with only minor interferences.

The additional cables and charging stations are then implemented step-wise according to the rising in the market share of EVS. The number of steps defines the flexibility of the design. If the number of steps is rather low, the design is less flexible. If the implementation of cables and charging facilities is done within many steps, the flexibility of the design is higher. But at some point, it is not practical anymore. Another aspect to consider for the number of steps is the spatial division of the parking garage. Since the parking garage consists of 4 levels, which are assumed to be identical, the step-wise implementation within 4 steps, and within 8 steps is examined. Therefore, for the implementation within 4 steps, cables and charging facilities are implemented on one whole level of the parking garage for each step. For the 8-step-implementation, the cables and charging facilities are brought in for the half of a level per step.

The market share functions as an indicator for the triggering for the step-wise implementation. It is chosen, that the market share is generally lower than the percent of implemented electrical parking spaces.

To account the already existing market share of EVs, an initial implementation of a certain number of electrical parking spaces is possible. The market share in 2017 is shown in Figure 2 and has a value of 0.32%. This yields to an initial demand of 1.47 electrical parking spaces. Since the value needs to be an integer, it is rounded up to 4 initial electrical parking spaces. This is done to keep the number of yet-to-be-implemented parking spaces dividable by 4 or 8. The amount of later implementable electrical parking spaces is therefore 456.

The information about the step-wise implementation for both versions can be seen in Table 3. “MS” indicates, at which market share the implementation is initiated. “%” describes the cumulated percentage of implemented electrical parking spaces at the corresponding step regarding the total amount of parking spaces, which is 460. “#” stands for the number of electrical parking spaces implemented at the corresponding step.

Table 3: Thresholds of 4-step and 8-step-implementation

4-step-implementation			**8-step-implementation**					
MS	%	#	MS	%	#	MS	%	#
15.0	25.7	114	10.0	13.3	57	60.0	62.8	57
40.0	50.4	114	22.5	25.6	57	72.5	75.2	57
65.0	75.2	114	35.0	38.0	57	85.0	87.6	57
90.0	100.0	114	47.5	50.4	57	97.5	100.0	57

It can be seen, that in both cases the steps are uniformly. For the 4-step-implementation the first threshold is a market share of 15 % of EVs. The next steps are triggered for every 25 % of gain in market share. With every step 10% more electrical parking spaces are implemented than actual needed. It can be seen, that there are at most 10 % too many electrical parking spaces, and at most 15 % too many traditional parking spaces implemented.

The first threshold for the 8-step-implementation is a market share of 10 % of EVs. Every following implementation is triggered after a gain of 12.5 % in market share. It can be seen, that there are just slightly too many electrical parking spaces after every implementation. This counteracts the implementation of too many electrical charge facilities. Whereas the percentage of too many traditional parking spaces are always around 10 %.

Another aspect to consider for the flexible design is the applied policy by the owner. Since both situations, namely Situation A and Situation B, are possible to occur within the examined period of 60 years, there are both policies applicable to the flexible design as well.

5.5.5 Summary of the defined designs

This section summarizes the defined designs again to have an overview over all designs with their corresponding varieties.

5.5.5.1 Traditional Design

The Traditional Design is a non-flexible design, in which the parking garage is implemented traditionally without any electrical parking spaces. A certain percentage of unsupplied EV users will not park at the parking garage, since there are no electrical charge facilities.

5.5.5.2 Maximum Design – Policy 1

The Maximum Design with Policy 1 is a non-flexible design, in which all parking spaces of the garage are implemented with electrical charge facilities right at the beginning. A certain percentage of unsupplied traditional users will not park at the parking garage, since they have to pay more than for a traditional parking space.

5.5.5.3 Maximum Design – Policy 2

The Maximum Design with Policy 2 is a non-flexible design, in which all parking spaces of the garage are implemented with electrical charge facilities right at the beginning. It is assumed, that all unsupplied traditional users will park at the parking garage, since they are able to park for the same rent as for a traditional parking space.

5.5.5.4 Flexible Design, 4-step-implementation – Policy 1

The Flexible Design with Policy 1, which is fully implemented within 4 steps, is a flexible design, in which the parking garage is built traditionally, with the addition of already brought in empty conduits. The cables and charging stations can be implemented at a later time, when the market share rises. Initially there are four parking spaces with already implemented charging stations. A certain percentage of unsupplied traditional users, as well as EV users, are not willing to park at the parking garage, since their needs are not fulfilled.

5.5.5.5 *Flexible Design, 4-step-implementation – Policy 2*

The Flexible Design with Policy 2, which is fully implemented within 4 steps, is a flexible design, in which the parking garage is built traditionally, with the addition of already brought in empty conduits. The cables and charging stations can be implemented at a later time, when the market share rises. Initially there are four parking spaces with already implemented charging stations. A certain percentage of unsupplied EV users, are not willing to park at the parking garage, since there are not enough parking spaces with charging facilities. On the other hand, all unsupplied traditional users are willing to park at the parking garage, since they are able to park for the same rent as for a traditional parking space.

5.5.5.6 *Flexible Design, 8-step-implementation – Policy1*

The Flexible Design with Policy 1, which is fully implemented within 8 steps, is analogue to the Flexible Design with Policy 1 implemented within 4 steps. The only difference is, that all electrical charge facilities are implemented within 8 steps instead of 4.

5.5.5.7 *Flexible Design, 8-step-implementation – Policy 2*

The Flexible Design with Policy 2, which is fully implemented within 8 steps, is analogue to the Flexible Design with Policy 2 implemented within 4 steps. The only difference is, that all electrical charge facilities are implemented within 8 steps instead of 4.

5.6 Establishment of static model

As stated in section 5.2 the LOS is to maximize the benefit of the owner. Therefore, a static model is established to express the benefit of the owner over the examined period of 60 years.

The benefit of the owner is expressed with Equation 1, which can be seen below. It is the summation of the benefits of each year within the 60 year period and the initial costs of the design. The benefit of each year is the summation over all income and costs within that year, whereas the income is accounted as positive and the costs as negative. The discount rate is chosen to be discrete, since the benefit is calculated annually (Zenou 2006).

Equation 1: Benefit of owner

$$B_t = \sum_{t=0}^{T} \left(\underbrace{(Income_{Trad.} + Income_{Elec.} + Cost_{Trad.} + Cost_{Elec.} + Cost_{Int.})}_{benefit\ for\ year\ t} * \underbrace{\frac{1}{(1+r)^t}}_{\substack{Discount \\ factor}} \right) + Cost_{Initial}$$

$$Income_{Trad.} = ps_{Trad.\,used} * Rent_{Trad.} \qquad Income_{Elec.} = ps_{Elec.\,used} * Rent_{Elec.}$$

$$Cost_{Trad.} = ps_{Trad.} * Maintain._{Trad.} \qquad Cost_{Elec.} = ps_{Elec.} * Maintain._{Elec.}$$

$$Cost_{Int.} = ps_{new} * (C_C * (1 + p_{add}) + C_{CS})$$

$$Cost_{Initial} = C_{EC} * ps_{Elec.\ total} + (C_C + C_{CS}) * ps_{Elec.\ initial}$$

Where;

$ps_{Trad.\,used}$ - number of used traditional parking spaces [-]

$ps_{Elec.\,used}$ - number of used electrical parking spaces [-]

$ps_{Trad.}$ - number of implemented traditional parking spaces [-]

$ps_{Elec.}$ - number of implemented electrical parking spaces [-]

ps_{new} - number of newly implemented electrical parking spaces [-]

$ps_{Elec.\ total}$ - total number of electrical parking spaces to be implemented [-]

$ps_{Elec.\ initial}$ - number of initially implemented electrical parking spaces [-]

$Rent_{Trad.}$ - Rent for a used traditional parking space for a year [CHF/year]

$Rent_{Elec.}$ - Rent for a used electrical parking space for a year [CHF/year]

$Maintain._{Trad.}$ - Maintenance costs for an implemented traditional parking space [CHF/year]

$Maintain._{Elec.}$ - Maintenance costs for an implemented electrical parking space [CHF/year]

C_{EC} - Cost of empty conduits for one electrical parking space [CHF/parking space]

C_C - Cost of cables for one electrical parking space [CHF/parking space]

C_{CS} - Cost of charging station for one electrical parking space [CHF/parking space]

p_{add} - percentage of additional cost for a later implementation of the cables, assumed to be 0.05

r - discount rate, assumed to be 0.03

t - year [-]

The income is the rent of traditional and EV users. The costs are the maintenance costs for the parking spaces. There needs to be a distinction between actually used parking spaces and implemented parking spaces for either type. Since some users might not park at the garage, there could be some unused parking spaces, which need to be considered regarding the maintenance, but will not generate any income. The costs for an intervention are the costs, which are induced by implementing additional electrical charging facilities as the market share rises. It is assumed, that the drawing-in of the cables takes more time, if the parking garage is already in operation. This is taken into account with a percentage of additional costs p_{add}. The initial costs are the costs for the empty conduits for all the electrical parking spaces and the costs of the initial implemented electrical parking spaces. Since the parking garage is not in operation yet, there is no need to add p_{add}.

5.7 Establishment of dynamic model

Based on the static model established in the previous section, a dynamic model is set up. For the dynamic model the varying of the key parameters are considered, whereas a period of 60 years is examined.

5.8 Estimation of costs for each design

The required values for the determination of the benefit of each design, can be seen in Equation 1. The required values are the initial costs, the intervention costs, the maintenance costs and the income from the rent. In the following sections each of these costs and incomes will be estimated. To estimate the initial and intervention costs the implementation costs are determined generally. Afterwards the initial and intervention costs for each design is calculated.

5.8.1 Implementation costs

As in section 5.4 stated, the implementation of the electrical charge facility on the parking spaces requires empty conduits, cables and the charging stations. The costs for the empty conduits and the cables are estimated per meter, whereas there is a material and a labor component for both. Then the required length per parking space is determined. With that the implementation cost for one parking space on average can be calculated.

For the empty conduits material costs of 1.95 CHF/m are estimated. The material costs for the cables are 1.30 CHF/m. It takes 0.4 hours to bring in one meter of empty conduits, respectively 0.07 hours to implement one meter of cable (AECOM 2015). For both tasks an hourly wage rate of 60 CHF is assumed (Renovero 2017). Furthermore, it is determined that roughly 17.4 m of each, empty conduits and cables, are needed to implement an electrical charge facility at a parking space on average. The detailed calculation of the material and labor component, and the required length per parking space can be seen in the Annexes.

Equation 2 and Equation 3 show the costs for the empty conduits and the cables per parking space. The costs for the implementation of the empty conduits are calculated to be 451 CHF per parking space, respectively 96 CHF per parking space for the cables.

Equation 2: Implementation costs for empty conduits per parking space

$$C_{EC} = \left(1.95\frac{CHF}{m} + 0.4\frac{h}{m} \cdot 60\frac{CHF}{h}\right) \cdot 17.4m = 451\ CHF/parking\ space$$

Equation 3: Implementation costs for cables per parking space

$$C_{C} = \left(1.30\frac{CHF}{m} + 0.07\frac{h}{m} \cdot 60\frac{CHF}{h}\right) \cdot 17.4m = 96\ CHF/parking\ space$$

The third part of the implementation costs are the costs of the charging station. Currently a charging station is available for roughly 700 to 1’500 CHF. The difference in price is mainly caused by the difference in power, which affects the charging time . Since the charging stations are implemented by the owner of the parking garage, it is assumed, that a charging station in the middle price range is chosen. Therefore, the owner provides an adequate service for the user, which means in this case, charging stations with an acceptable charge time, while the costs for a charging station is affordable for the owner. The costs of the charging station is therefore assumed to be 1’000 CHF. Additionally to the material costs for the charging station, there are costs for the installation as well. These installation costs are estimated to be 200 CHF (The Mobility House 2017). This leads to the initial implementation costs for a charging station for one parking space of 1’200 CHF. It can be seen, that compared to the costs of the empty conduits and the cables, the costs of the charging station are high. Therefore, the costs of the charging station have a considerable influence on the benefit of a design, as it is explained in subsection 5.3.3. Because of that, and because the costs of the charging stations are certainly going to drop with a rise in market share of EVs, the costs of a charging station are modelled as a key parameter, as it is done in subsection 5.3.3.

In the following two subsubsections, the initial costs and the intervention costs of each design are calculated.

5.8.1.1 Initial costs

The initial costs are calculated for each design with the according part of Equation 1;

$$Cost_{Initial} = C_{EC} * ps_{Elec.\ total} + (C_C + C_{CS}) * ps_{Elec.\ initial}$$

with the previously calculated costs and with the initial value for the costs of a charging station of 1’200 CHF the Equation is:

$$Cost_{Initial} = 451 * ps_{Elec.\ total} + (96 + 1200) * ps_{Elec.\ initial}$$

Where $ps_{Elec.\ total}$ and $ps_{Elec.\ initial}$ differs for every design.

Table 4 shows the corresponding initial costs for every design depending on their total number of electrical parking spaces to be implemented $ps_{Elec.\ total}$ and the number of initially implemented electrical parking spaces $ps_{Elec.\ initial}$.

Table 4: Initial costs of each design depending on their total number of electrical parking spaces to be implemented and number of initially implemented electrical parking spaces

Design	$\boldsymbol{ps_{Elec.\ total}}$	$\boldsymbol{ps_{Elec.\ initial}}$	**Initial costs**
Traditional	-	-	- CHF
Maximum	460	460	803’620 CHF
Flex 4	460	4	212’644 CHF
Flex 8	460	4	212’644 CHF

5.8.1.2 Intervention costs

The intervention costs of each design can be calculated analogously with the corresponding part of Equation 1;

$$Cost_{Int.} = ps_{new} * (C_C * (1 + p_{add}) + C_{CS})$$

with the previously calculated costs for the cables and assumed p_{add} to be 0.05, the equation is:

$$Cost_{Int.} = ps_{new} * (96 * (1 + 0.05) + C_{CS})$$

It needs to be mentioned that the costs of the charging station are uncertain and changes according to the market share. Therefore, there is no determined value for C_{CS}. Nevertheless the static part of the equation can be calculated for each design. The intervention costs, without the costs of the charging stations, are shown in Table 5.

Table 5: Intervention costs of each design depending on their number of newly implemented electrical parking spaces per step without the costs of the charging stations

Design	Steps	ps_{new}	Intervention costs per step	Intervention costs total
Traditional	-	-	- CHF	- CHF
Maximum	-	-	- CHF	- CHF
Flex 4	4	114	11’492 CHF	45’968 CHF
Flex 8	8	57	5’746 CHF	45’968 CHF

5.8.2 Maintenance costs

The maintenance costs resemble the expenses for cleaning the parking garage annually. It is assumed, that it takes 16 labor hours to clean one entire level. Again, an hourly wage rate of 60 CHF is assumed. Additional to the cleaning costs, expenses for the controlling of the electrical system, meaning the cables and the charging stations themselves, are considered for electrical parking spaces. It is assumed, that the controlling is executed every 5 years and takes 24 labor hours per level. The hourly wage for a higher trained electrician, which is needed for the controlling, is 115 CHF (Baumann Elektrokontrollen 2018). With a total of 4 levels and 460 parking spaces, the maintenance costs for traditional and electrical parking spaces are calculated in Equation 4 and Equation 5.

Equation 4: Maintenance costs for one traditional parking space per year

$$Maint._{Trad.} = \left(16\frac{h}{Level} \cdot 60\frac{CHF}{h} \cdot 4\ Level\right)/460\ ps = 8.30\ \frac{CHF}{parking\ space\ \cdot year}$$

Equation 5: Maintenance costs for one electrical parking space per year

$$Maint._{Elec.} = 8.3 + \frac{\left(24\frac{h}{Level} \cdot 115\frac{CHF}{h} \cdot 4\ Level\right)}{460 \cdot 5\ years} = 13.10\ \frac{CHF}{parking\ space\ \cdot year}$$

The maintenance costs for a traditional parking space are 8.3 CHF per year, respectively 13.1 CHF per year for an electrical parking space. Other kind of maintenance or operation costs are not considered, since they would be the same for both types of parking spaces.

5.8.3 Rent

The rent for a traditional parking space is taken from the case study and is known to be 1452 CHF per year (Elvarsson 2018). The rent for an electrical parking space is calculated with the rent of a traditional parking space, with the addition of 10 % of the implementation costs per parking space. This resembles an amortization of 10 years of the invested costs. As the costs of a charging station is not static and change according to the market share of EVs, the implementation costs and therefore the rent of an electrical parking space varies. To simplify the calculation the initial value for the charging station of 1’200 CHF is considered for the implementation costs, with which the rent of the electrical parking space is calculated. Equation 6 shows the calculation of the rent of the electrical parking space, which is 1627 CHF per year.

Equation 6: Rent for one electrical parking space per year

$$Rent_{Elec.} = 1452 + \frac{(451 + 96 + 1200)\,\frac{CHF}{parking\ space}}{10\ years} = 1627\ \frac{CHF}{parking\ space\ \cdot year}$$

5.8.4 Summary of the costs of each design

The calculated costs are summarized for each design in Table 6.

Table 6: Summary of the costs of all designs

Design	[CHF]		[CHF/year/parking space]	Trad.	Elec.
Traditional	Initial	-	Maintenance	8.30	-
	Intervention	-	Rent	1’452	-
Maximum	Initial	803’620 CHF	Maintenance	-	13.10
	Intervention	-	Rent	-	1’627
Flex 4	Initial	212’644 CHF	Maintenance	8.30	13.10
	Intervention	11’492 CHF	Rent	1’452	1’627
Flex 8	Initial	212’644 CHF	Maintenance	8.30	13.10
	Intervention	5’746 CHF	Rent	1’452	1’627

5.9 Estimation of benefits of each design

For each design different scenarios are simulated. The simulations are done with the Monte Carlo method, whereas for every design 1000 simulation are carried out. Table 7 shows the mean and the standard deviation of the benefit of each design. It can be seen, that the Maximum design with Policy 1 has the lowest benefit of 9’343’432 CHF. After that comes the Traditional design with a benefit of 16’084’702 CHF. The Maximum Design with Policy 2 and the flexible designs have a relatively high benefit. The benefit of the designs ranges from 18.8 Mio to 19.1 Mio. CHF, whereas the Flex 8 Design with Policy 2 has the highest benefit with 19'137'521 CHF. The standard deviation displays the same. The deviation for the Maximum Design with Policy 1 has the highest deviation of all designs, which indicates a high instability. The Traditional Design is again better than the Maximum with Policy 1, but still has a high standard deviation of 1’169’470 CHF. The standard deviations for the other designs are again quite narrow together. They vary from 318’602 CHF down to 201’760 CHF, whereas the Flex 8 Design with Policy 2 has the lowest standard deviation.

Table 7: Mean and standard deviation of each design in CHF

Design	**Policy**	**Mean**	**Deviation**
Traditional	-	16'084'702 CHF	1'169'470 CHF
Maximum	Policy 1	9'343'432 CHF	2'907'854 CHF
	Policy 2	18'977'275 CHF	318'602 CHF
Flex 4	Policy 1	18'787'131 CHF	244'707 CHF
	Policy 2	19'056'975 CHF	221'028 CHF
Flex 8	Policy 1	19'077'512 CHF	211'402 CHF
	Policy 2	19'137'521 CHF	201'760 CHF

Figure 20 shows graphically the mean and the cumulative probability of the benefit of the seven examined designs. The curved lines show the cumulative probability of the benefit of each design. The vertical line indicates the mean. The slope of the curve of the cumulative probability of the benefit indicates the standard deviation, whereas a steep curve indicates a small standard deviation. It can be seen, that the Traditional Design and the Maximum Design with Policy 1 are the designs with the lowest benefit. The other designs are fairly close to each other. Figure 21 shows the same graph as Figure 20, except it only displays the range of 18.0 Mio. to 19.5 Mio. CHF, for a better comparing of the most beneficial designs, namely the Maximum Design with Policy 2 and the four variations of the flexible designs.

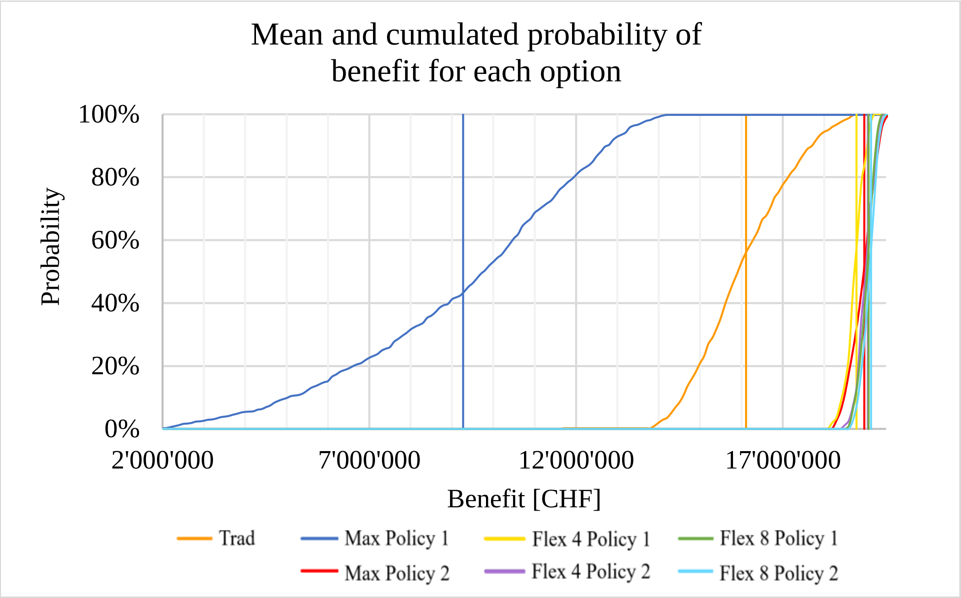

Figure 20: Mean and cumulative probability of benefit for each design

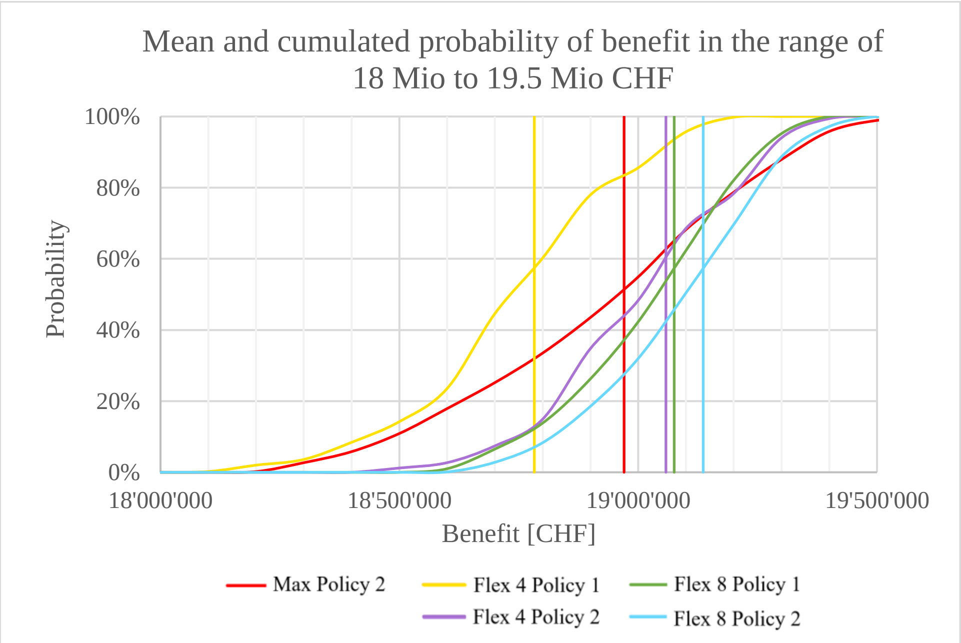

Figure 21: Mean and cumulative probability of benefit in the range of 18 Mio. to 19.5 Mio. CHF

6 Results and Discussion

The discussion of the results is done in three parts. At a first part the Maximum Design with Policy 1 is discussed individually. For the second part the Traditional Design is examined and compared to the Maximum Design with Policy 1. At last the high beneficial designs, namely the Maximum Design with Policy 2, the Flex 4 Design and the Flex 8 Design, both with either policy, are discussed and compared to each other.

6.1 Discussion on Maximum Design with Policy 1

The Maximum Design with Policy 1 is the least beneficial of all designs. With a mean benefit of 9'343'432 CHF and a standard deviation of 2'907'854 CHF the Maximum Design with Policy 1 is the least preferable one. The high standard deviation indicates a fairly high uncertainty regarding the actual benefit of this design.

For the Maximum Design all parking spaces of the parking garage are implemented right at the beginning with electrical charge facilities. This leads not only to high initial costs, but to a high number of unused electrical parking spaces at the first years as well. Especially the implementation of the charging stations, which are a substantial part of the implementation costs, are quite cost-effective, since they are implemented for their initial price of 1’200 CHF right at the beginning. Therefore, a lowering in costs for the charging stations associated with the further development of the EV technology is not considered.

The high number of unused parking spaces has two causes. The first cause is the simple reason, that there are no traditional parking spaces, but the demand of traditional parking spaces is high during the first years, since the market share of EVs is still quite low. Therefore, there is a high number of unsupplied traditional users. The second cause is the application of the Policy 1. As explained in subsubsection 5.5.1.1, the Policy 1 is rather not user-friendly. The unsupplied traditional users need to rent an electrical parking space at higher rent, even though they do not need it. And since the acceptance of the traditional users at the beginning is rather low, the number of unused parking spaces is high. Therefore, the number of unused parking spaces can be explained with the combination of the Maximum Design with the application of Policy 1. Whereas the high number of unused parking spaces at the beginning leads to substantial loss in benefit. The impact of this loss in benefit and the previously mentioned initial costs are even higher, since they occur at the beginning of the examined 60-year-period and are therefore more cost-effective. This leads to the low benefit of this design.

Additionally it can be seen, that the benefit can vary greatly. Since the design is not flexible, it doesn't depend if the development in market share for the EVs is low or high. The design is always the same. But as the market share development changes throughout the different simulations, the benefit varies. If a high development in market share is simulated, the benefit is quite high as well, since there is a higher demand in electrical parking spaces. Furthermore, a high market share in EVs also increases the acceptance of the traditional users, which again leads to less unused parking spaces. On the other side, if a low development in market share is simulated, the benefit is fairly low, since the demand of electrical parking spaces is low as well. This inability to adapt towards the market share development makes the benefit of the design quite uncertain, which is represented with a high standard deviation.

6.2 Discussion on Traditional Design

The Traditional Design is the design with the second lowest benefit. It has a mean benefit of 16'084'702 CHF and a standard deviation of 1'169'470 CHF. The high standard deviation indicates a rather high uncertainty regarding the actual benefit of this design as well.

For the Traditional Design the parking garage is implemented traditionally with only traditional parking spaces. The relatively low benefit can be explained with the high number of unused parking spaces as well. Since the Traditional Design has only traditional parking spaces and the market share of EVs at the first years is quite low, the number of unused parking spaces is low as well. Therefore, the loss in benefit is low within the first years of the examined period too. Then with an increase in market share of EVs the number of unused parking spaces rises, since the number of unsupplied EV users rises and their acceptance to rent a traditional parking space decrease. But this has not such a huge impact as for the unused parking spaces in the Maximum Design with Policy 1, since the benefit is discounted according to the years, which makes it less influencing. Therefore, it makes a difference, at which the time these unused parking spaces occur. Because of the discount factor the same losses in benefit can't be counted equally, if they occur at different points in time. This can be seen in Figure 22. It shows, as an example, the number of unused parking spaces for a low ($r_{ms} = 0.05$) and for a high ($r_{ms} = 0.95$) development in market share of EVs for the Traditional Design, displayed in orange, and for the Maximum Design with Policy 1 displayed in blue. It can be seen, that the Traditional Design has less unused parking spaces at the beginning, and many at the end. For the Maximum Design with Policy 1 it's the opposite way around. The discount factor throughout the years can be seen in the lower diagram.

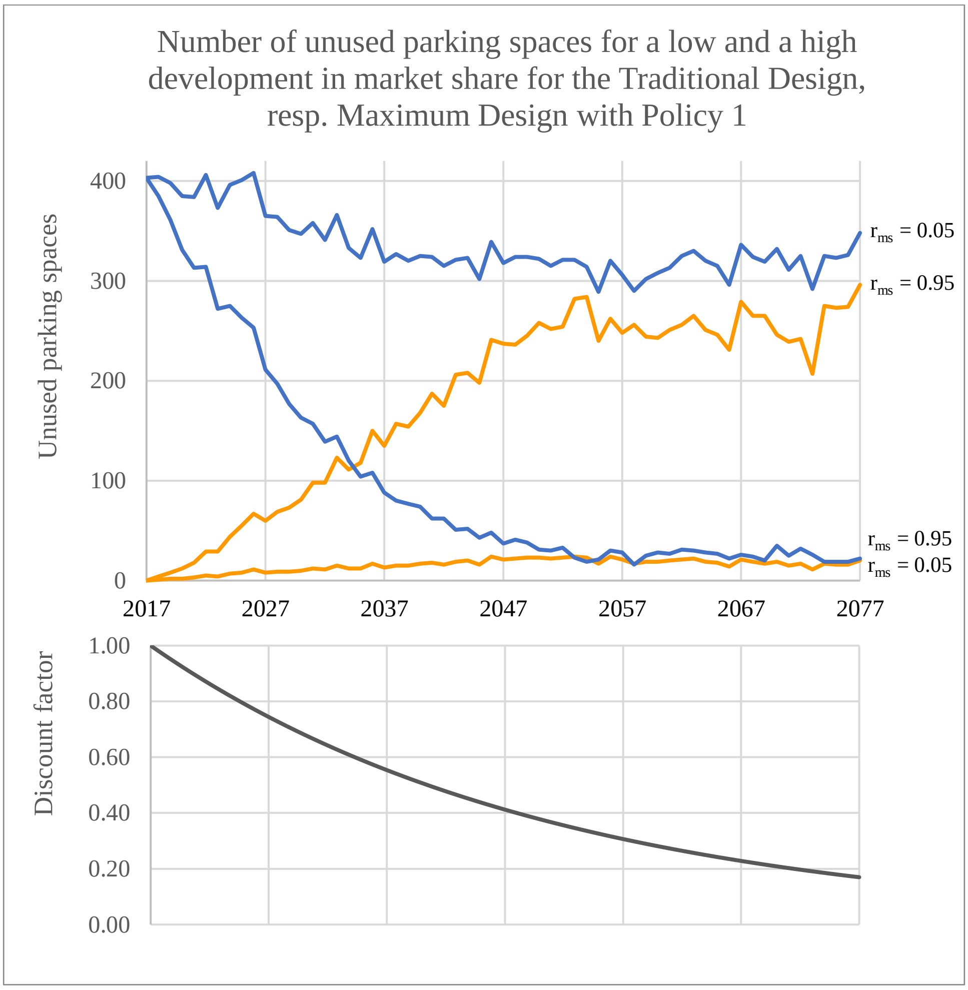

Figure 22: Number of unused parking spaces for a low and a high development in market share for the Traditional Design in orange, respectively Maximum Design with Policy 1 in blue (diagram above), Discount factor (diagram below)

As said before, the discount factor has a considerable influence on how much an income or a spending affects the benefit. Therefore, the discount factor can be used to weight the unused parking spaces to reflect their influence on the benefit throughout the examined period. The weighted numbers of parking spaces for the Traditional and the Maximum Design is shown in Figure 23. Due to the weighting factor the numbers of unused parking spaces at the second half of the examined period is quite low. The two vertical black lines indicate two points in time, the year 2027, which should serve as an example for an early time, and the year 2067 for a late time example within the examined 60 years.

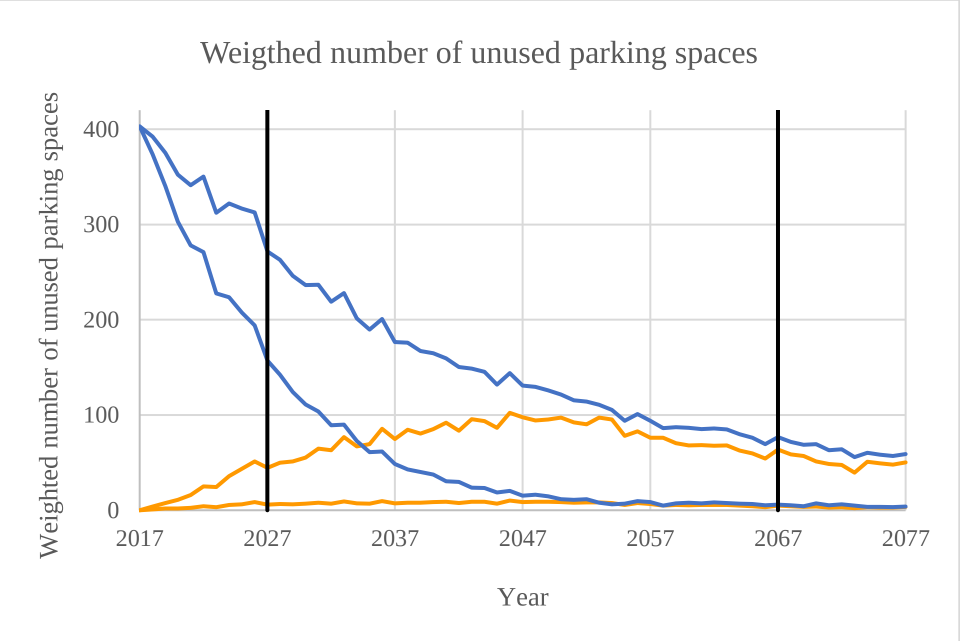

Figure 23: Number of unused parking spaces weighted

In Figure 23 can be seen, that the number of weighted unused parking spaces for the Maximum Design with Policy 1 is for both cases, a low development and a high development of the market share, generally higher, than for the Traditional Design. Especially within the early years the unused parking spaces are substantial higher for the Maximum Design.

The weighted unused parking spaces for the low and the high development in market share for the year 2027 and 2067 can be seen in Table 8. It shows, that in year 2027 the number of weighted unused parking spaces and therefore the loss in benefit is substantially higher for the Maximum Design with Policy 1. At a later time, in year 2067, both designs have nearly the same values for the low and the high development of the market share.

Table 8: Weighted unused parking spaces for a low and a high market share development for year 2027 and 2067 for the Traditional Design and for the Maximum Design with Policy 1

	2027		2067	
Traditional Design	Low development	6.0	Low development	4.8
	High development	44.6	High development	63.6
	Difference	38.6	Difference	58.8
Maximum Design with Policy 1	Low development	157.0	Low development	5.9
	High development	271.6	High development	76.6
	Difference	114.6	Difference	70.7

Since the weighted unused parking spaces represent the influence of an unused parking space on the benefit depending on its occurrence, it can be said, that because of the substantially higher number of weighted unused parking spaces at the beginning of the examined period, the Maximum Design with Policy 1 has a fairly lower benefit over the 60-year period, that the Traditional Design. Another aspect why the Traditional Design has a higher benefit than the Maximum Design with Policy 1 is, that there are no initial costs, which make a difference of around 800'000 CHF instantly. But nevertheless, due to the high number of unused parking spaces, the benefit of the Traditional Design is still lower than for the five most beneficial designs.

As for the Maximum Design with Policy 1, the benefit has a significant uncertainty within. This uncertainty is also caused by the fact, that the Traditional Design is a non-flexible design. Therefore, the design can't adapt according to the change in market share of EVs. If the development of the market share of EVs is low, the benefit would be high, and vice-versa. However, the standard deviation is not as high as for the Maximum Design with Policy 1. This is indicated by the differences of the weighted values for the low and the high development, which can be seen in Table 8 as well. The differences in the weighted value indicate how much the benefit varies, if a low development or a high development of the market share is simulated. Therefore, it can be said, that the higher the difference, the higher the variation of benefit will be, which is displayed to the standard deviation. Table 8 shows, that for the Traditional Design the difference between the low and the high development is 38.6 unused parking spaces in year 2027 and 58.8 in year 2067. The difference of the two developments for the Maximum Design is 114.6 in year 2027 and 70.0 in year 2067. Therefore, the difference is substantially lower for the Traditional Design, which in turn indicates a lower standard deviation.

6.3 Discussion on high beneficial designs

In this third part of the discussion the five most beneficial designs are discussed and compared to each other. It is explained why the Maximum Design with Policy 2 can keep up with the other designs, even though it is not flexible. Furthermore, the difference between the two defined policies is discussed and the difference between a 4-step-implementation and an 8-step-implentation is analyzed.

Table 9 shows again numerically the mean and the standard deviation of the five most beneficial designs. Figure 24 shows, once again, the mean and the cumulated probability of benefit for the five most beneficial designs graphically.

Table 9: Mean and standard deviation of five most beneficial designs

Design	Policy	Mean	Deviation
Maximum	Policy 2	18'977'275 CHF	318'602 CHF
Flex 4	Policy 1	18'787'131 CHF	244'707 CHF
	Policy 2	19'056'975 CHF	221'028 CHF
Flex 8	Policy 1	19'077'512 CHF	211'402 CHF
	Policy 2	19'137'521 CHF	201'760 CHF

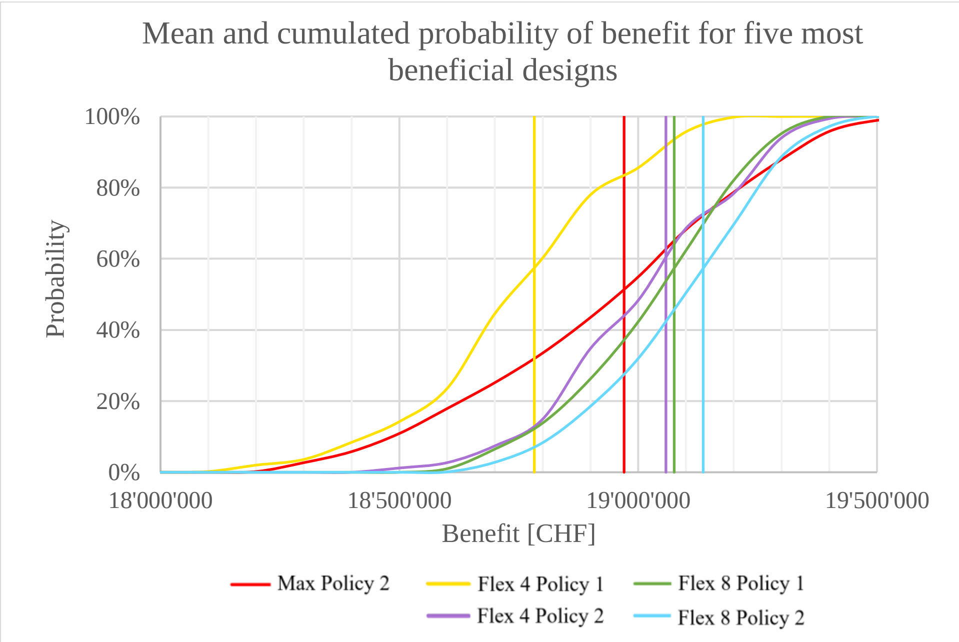

Figure 24: Mean and cumulated probability of benefit for five most beneficial designs

6.3.1 The keeping-up of the Maximum Design with Policy 2

The Maximum Design with Policy 2 is defined as a non-flexible design. Means the design can't adapt to a change in market share with the execution of interventions. However, this design stands out from the other non-flexible designs. It is the only non-flexible design with a comparably high benefit like the flexible designs. With a benefit of 18'977'275 CHF it has even a higher benefit than the Flex 4 Design with Policy 1. This is caused by the combination of the Policy 2 with the Maximum Design. For the Maximum Design all electrical charge facilities are implemented right at the beginning. This leads to a high number of unsupplied traditional users. But because of the application of Policy 2, all these unsupplied traditional users, will stay at the parking garage, because they can rent an electrical parking space for the same rent as a traditional one. This leads to a lower income per parking space, but since all the unsupplied traditional users will stay at the parking garage, the overall income, and therefore the benefit, is higher. This can be seen in the number of unused parking spaces as well. Since all unsupplied traditional users are assumed to rent an electrical parking space at lower rent, there are no unused parking spaces throughout the whole examined period of 60 years. The application of Policy 2 makes it therefore possible for the designs to be somehow flexible and adapt perfectly to the market share development. The reason why this design is still not the most beneficial one, is the fact, that the investment of the charging facilities is right at the beginning, where it has the greatest impact on the benefit due to the discounting. Furthermore, the money spend for the electrical charge facilities is always the same. This means, that if the market share development is low, there are less EV users, and therefore less income from electrical parking spaces. The spend money for most of the electrical charge facilities is then unnecessary, because the investment costs can't be retaken from the higher rent of electrical parking spaces. This leads to unnecessary investment, which in turn leads to higher costs and lower benefit.

The same thoughts can be made about the standard deviation. The standard deviation is with 318'602 CHF slightly higher than for the flexible designs. This is due to the fact, that at some simulations the investment for the electrical charge facilities at the beginning pays off, and for some simulation the investment can't be retaken from the higher rent of electrical parking spaces, since the market share of electrical vehicles stays low.

6.3.2 Difference between Policy 1 and Policy 2

Policy 1 and Policy 2 stipulate a difference in the handling of unsupplied traditional users. With Policy 1 some users will refuse to stay at the parking garage. However, they pay the full rent for the electrical parking space. On the other hand with Policy 2, all unsupplied traditional users stay at the parking garage, but at a lower rent. Which policy generates more benefit and why is not clearly at first. It is known, that the number of unused parking spaces have an influence on the benefit of the designs. Because Policy 1 and Policy 2 implies different behavior for only the unsupplied traditional users, just the number of unsupplied traditional users need to be analyzed to determine the difference of the two policies. Representatively the designs Flex 4 with Policy 1 and Flex 4 with Policy 2 are examined. It can be said, that for Policy 1 for every not accommodated unsupplied traditional user the loss is 1'627 CHF per year. For Policy 2 it is assumed, that for every accommodated unsupplied traditional user the loss is the difference in rent, therefore 175 CHF per year. If the loss is calculated with including the discount factor, the difference for the both policies can be displayed. The discounted loss in benefit for

Policy 1 and Policy 2 for a low development in market share (r_{ms} = 0.05) can be seen in Figure 25. A high development in market share (r_{ms} = 0.95) is represented in Figure 26.

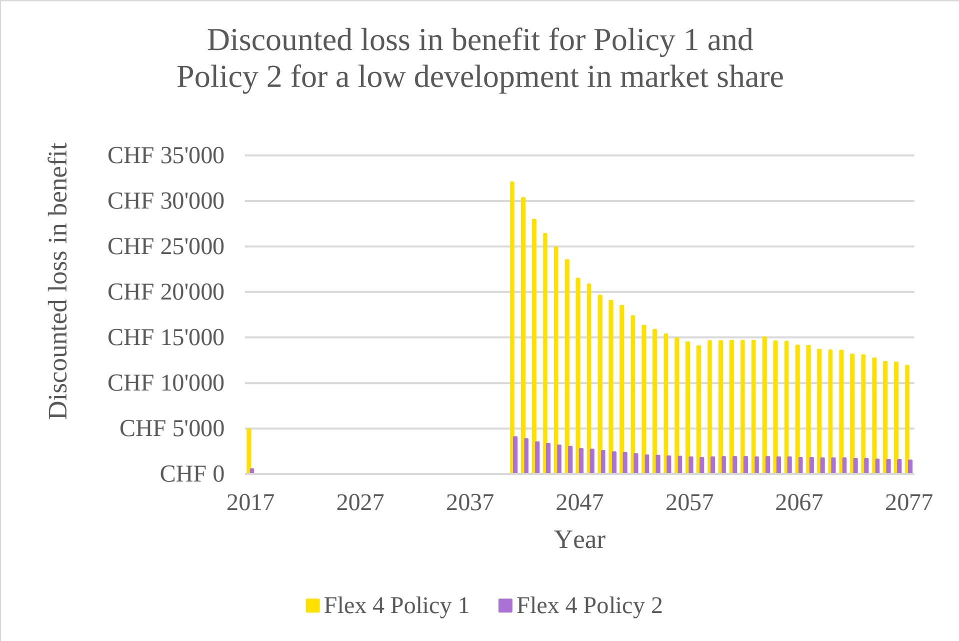

Figure 25: Discounted loss in benefit for Policy 1 and Policy 2 for low development in market share (r_{ms} = 0.05)

It can be seen, that for both cases, a low development in market share or a high development, the Policy 2 always yields to a lower loss than Policy 1. In Figure 25 can be seen, that in year 2041 an intervention is carried out, which increases the number of electrical parking spaces by 114. From this point on, there are plenty of electrical parking spaces, which are not needed. Applying Policy 1 leads to a significantly loss in benefit, since less users are willing to park at the parking garage. Whereas the application of Policy 2 leads to a fairly lower loss in benefit for the same situation, since all users are accommodated by the parking garage.

The same outcome can be seen in Figure 26. Policy 2 always leads to a lower loss in benefit than Policy 1. It can be seen, that after every intervention the loss of benefit increased instantly, since every intervention implements more electrical parking spaces than actually needed.

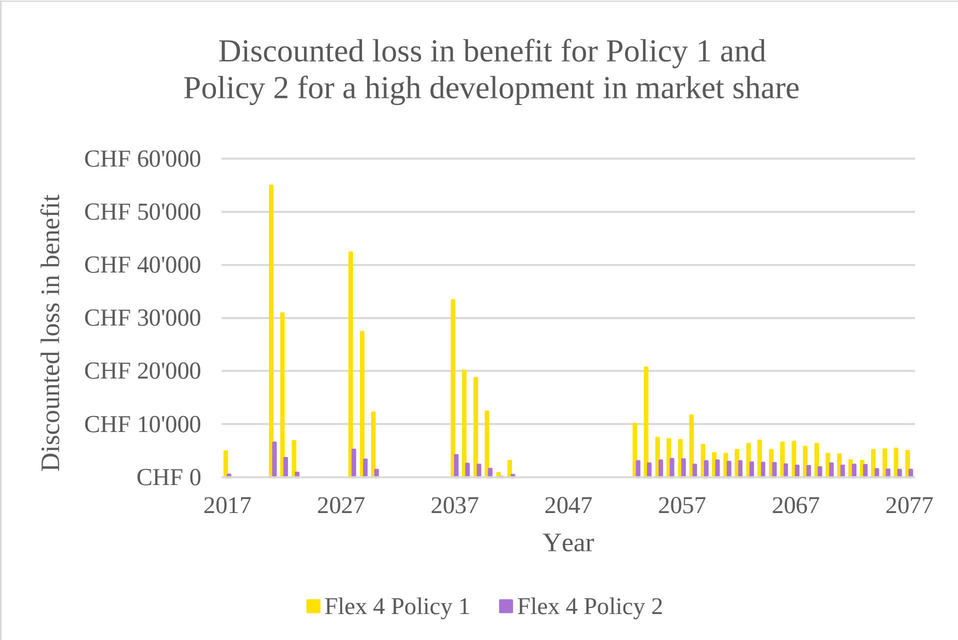

Figure 26: Discounted loss in benefit for Policy 1 and Policy 2 for high development in market share (r_{ms} = 0.95)

Therefore it can be said, that indifferent how the market share is developing, the Policy 2 is more beneficial than Policy 1. This is caused by the small difference in rent of just 175 CHF for the Policy 2, whereas the Policy 1 looses 1’627 CHF per unsupplied traditional users, which is not accommodated. Furthermore, it can be seen, that this difference in benefit depends on the number of electrical parking spaces, which are implemented within an intervention. The smaller the number of implemented spaces per intervention is, the smaller the difference between the benefit of the two policies. This is shown in Table 7, where as well as for the Maximum Design the difference in benefit for the two policies is the greatest with 9’633’843 CHF. With a decrease in number of implemented electrical parking spaces per intervention, the difference between the policies decreases. The difference for the Flex 4 Design is already significantly lower with 269’844 CHF. For the Flex 8 Design the difference between the benefit of the two policies drops to 60’009 CHF.

6.3.3 Difference between the 4-step and the 8-step-implementation

As seen in the previous subsection does the number of implemented electrical parking spaces per intervention have a considerable influence on the benefit of the designs. At each intervention more electrical charge facilities are implemented than currently needed. This is done to anticipate and to have enough electrical parking spaces the following years after the intervention. But as more charge facilities are implemented than needed, there are unsupplied traditional users, which in turn lead to a loss in benefit, as indicated in subsection 6.3.2. On the other hand, for the years before an intervention, there are too much traditional parking spaces and unsupplied EV users.

In Table 9 and in Figure 24 can be seen, that generally an 8-step-implementation is more beneficial than a 4-step-implementation. The 4-step-implementation implements 114 parking spaces at one intervention, whereas the 8-step-implementation only implements 57 at once. Therefore, the 8-step-implementation implements less unneeded electrical parking spaces, which leads to less unsupplied traditional users. On the other hand, the intervention is triggered faster for an 8-step-implementation, because the steps regarding the market share are smaller.

This means generally, that the better the design can adapt to the changing market share, the more beneficial a design is. Or with other words, the more flexible a design is, regarding the exact number of needed parking spaces of each type, the more benefit will be generated. The difference between the actual and the implemented number of electrical parking spaces for a relatively high development in market share (r_{ms}=0.85) can be seen in Figure 27 for the 4-step-implementation, and in Figure 29 for the 8-step-implementation. Additionally, Figure 28 and Figure 30 indicate graphically the deviation between the number of actual needed and implemented electrical parking spaces, whereas an undersupply of electrical parking spaces is seen as negative. In the figures is shown, that the 8-step-implementation can better adapt to the change in market share, since the number of over- and undersupplied electrical parking spaces is generally lower. Furthermore, it can be seen, that the trigger values for the 8-step-implementation are chosen to be in such a way, that there is just slightly over-dimensioning regarding the implemented number of electrical parking space. With this, the number of unnecessary implemented electrical charge facilities can be reduced, which again leads to a higher benefit for the design.

Moreover, the intervention costs for an 8-step-implementation are half of the intervention cost for a 4-step-implemenation, since just 57 electrical charge facilities are implemented at one intervention. This leads to the fact, that the intervention costs for an 8-step-implementation are lower and distributed more evenly throughout the examined 60-year-period. This is certainly preferred by the investors and by the owner of the parking garage.

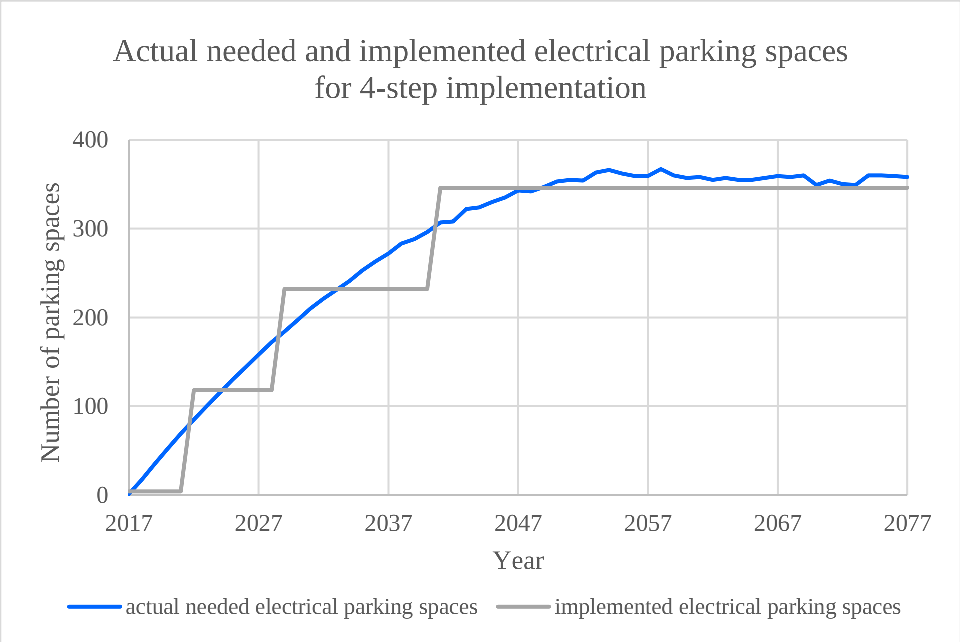

Figure 27: Actual needed and implemented electrical parking spaces for 4-step implementation

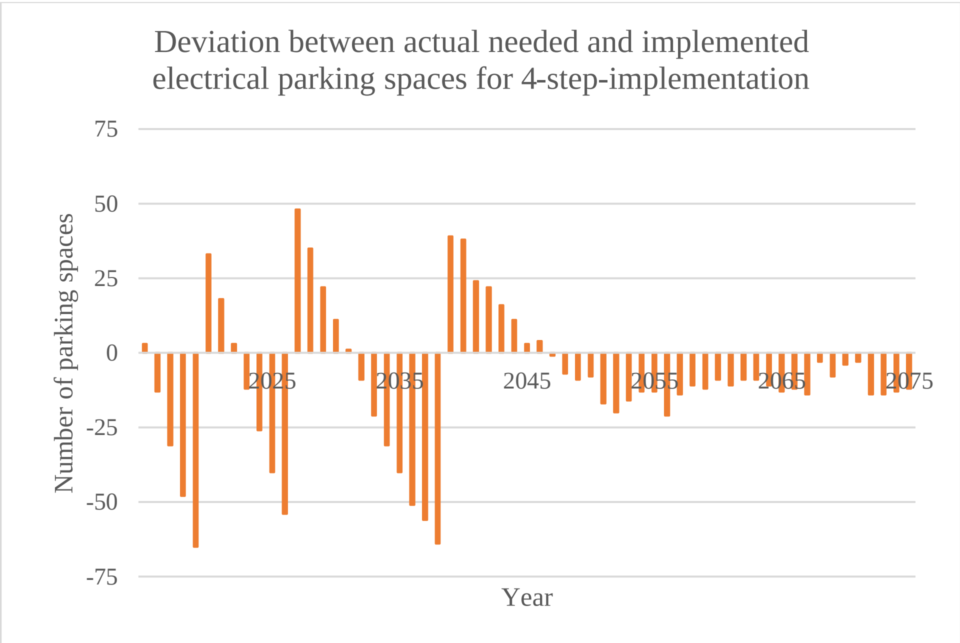

Figure 28: Deviation between actual needed and implemented electrical parking spaces for 4-step-implementation

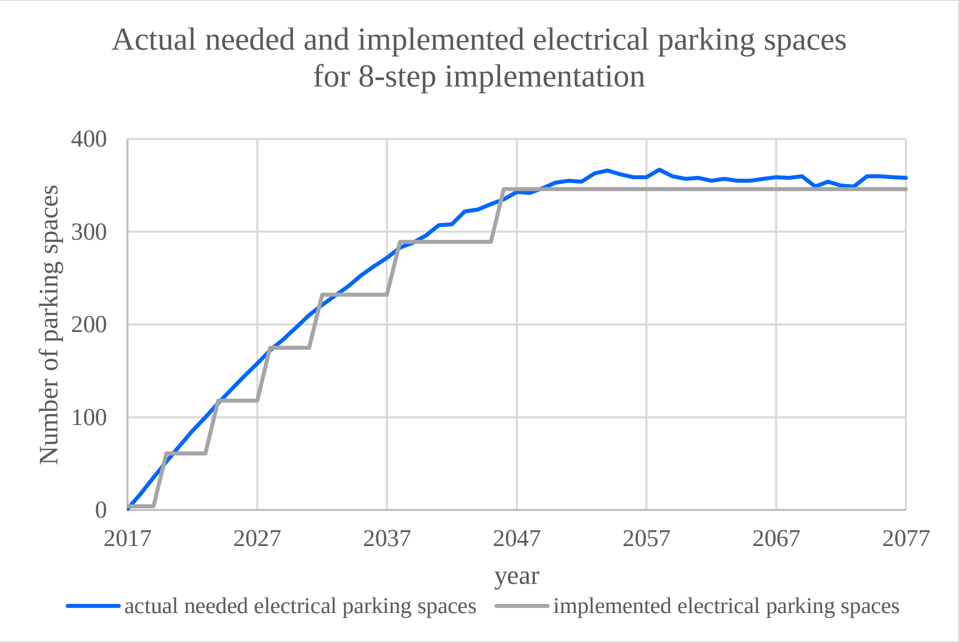

Figure 29: Actual needed and implemented electrical parking spaces for 8-step implementation

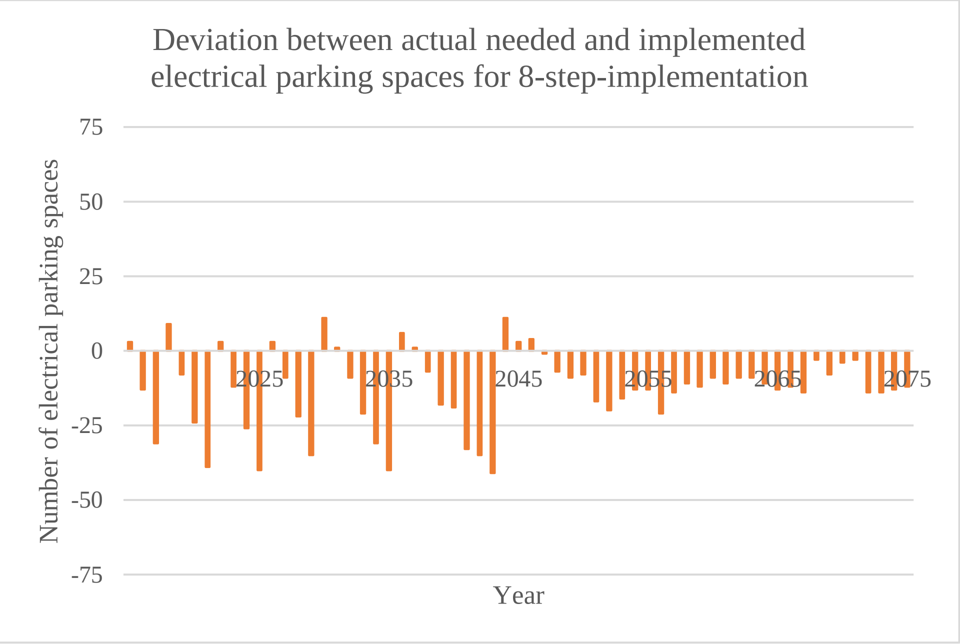

Figure 30: Deviation between actual needed and implemented electrical parking spaces for 8-step-implementation

Another aspect, which generally leads to slightly lower costs for the 8-step-implementation, is, that for the same amount of parking spaces the 4-step-implementation needs one intervention, whereas the 8-step-implementation needs two interventions. This yields to the fact, that the 4-step-implementation implements the same amount of electrical parking spaces earlier in time than the 8-step-implementation. Because the parking spaces are implemented later in time, the same amount of parking spaces yield to lower costs for the 8-step-implementation. This can be explained with two aspects. Firstly because of the discounting factor the effective intervention costs for the same amount of parking spaces decreases over time. And additionally, the costs of the charging station, which is a key parameter, decrease over time as well. The difference between the discounted intervention costs for the 4-step- and the 8-step-intervention for a relatively high market share development (r_{ms}=0.85) can be seen in Figure 31. It can be seen, that the later an intervention takes place, the lower the intervention costs are, even though the same amount of parking spaces are implemented for the design. Nevertheless, the impact of the time of the intervention on their costs is relatively small. If the intervention costs are summed up for each design, the difference is neglectable. The shown 4-step-implementation has overall intervention costs of 248’764 CHF. Whereas the 8-step-implementation has overall intervention costs of 245’060 CHF. It needs to be noted, that the interventions of both examined designs does not take place at the same time, since the triggers are defined for different values. If the triggers, which can be seen in Table 3, would be defined differently, the time of intervention, and therefore the costs of the interventions, would vary.

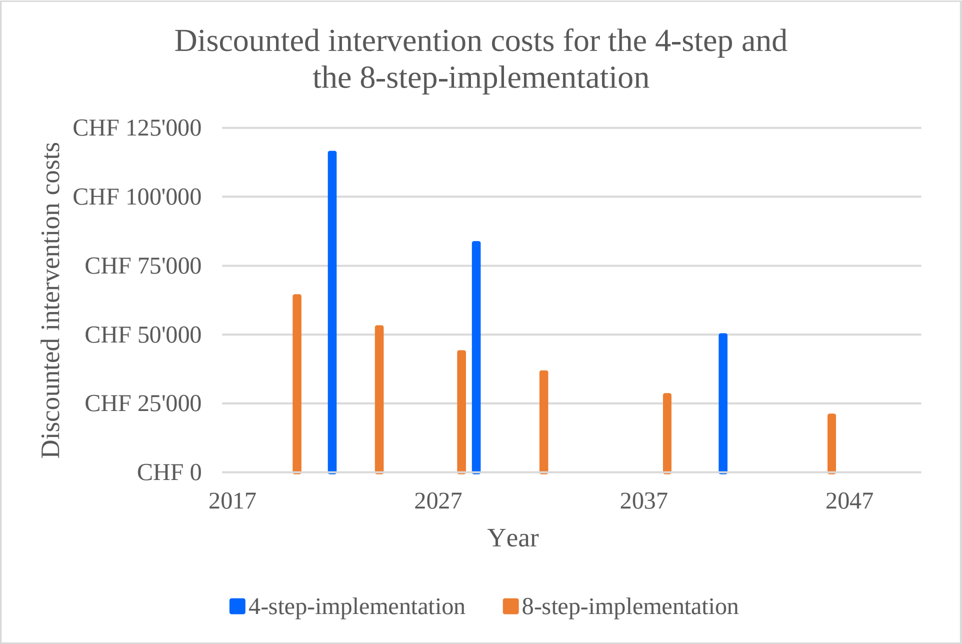

Figure 31: Discounted intervention costs for the 4-step and the 8-step-implementation

7 Sensitivity Analysis

Throughout the discussion in chapter 6 it becomes clear, that there are certain aspects, which influence the benefit of a design. The discount factor, respectively the discount rate, the number of unused parking spaces, the acceptance of the users, the implementation costs or the initial costs are just some of them. Since the discount rate has a fairly high influence on the benefit, a sensitivity analysis regarding the discount rate is done. Additionally a sensitivity analysis considering the acceptance of the EV users is carried out, since it is unknown, how unsupplied EV users would behave. At last the influence on the benefit of a design is analyzed, if the initial costs are substantial higher than assumed.

7.1 Discount rate

In chapter 6 it can be seen, that all impacts on the benefit (e.g. revenues, costs, unused parking spaces, etc.) are mostly influenced by the discount rate, respectively the discount factor. Therefore a sensitivity analysis regarding the discount rate is done. Initially a discount rate of 0.03 is assumed, which is normally considered. The sensitivity analysis is done for a lower discount rate r = 0.01, and a higher discount rate r = 0.05, which resembles more extreme, but still plausible, events, to see the impact on the benefit of the designs. The different discount factors, depending on the discount rate, can be seen in Figure 32. It can be seen, that the discount factor varies greatly if different discount rates r are used.

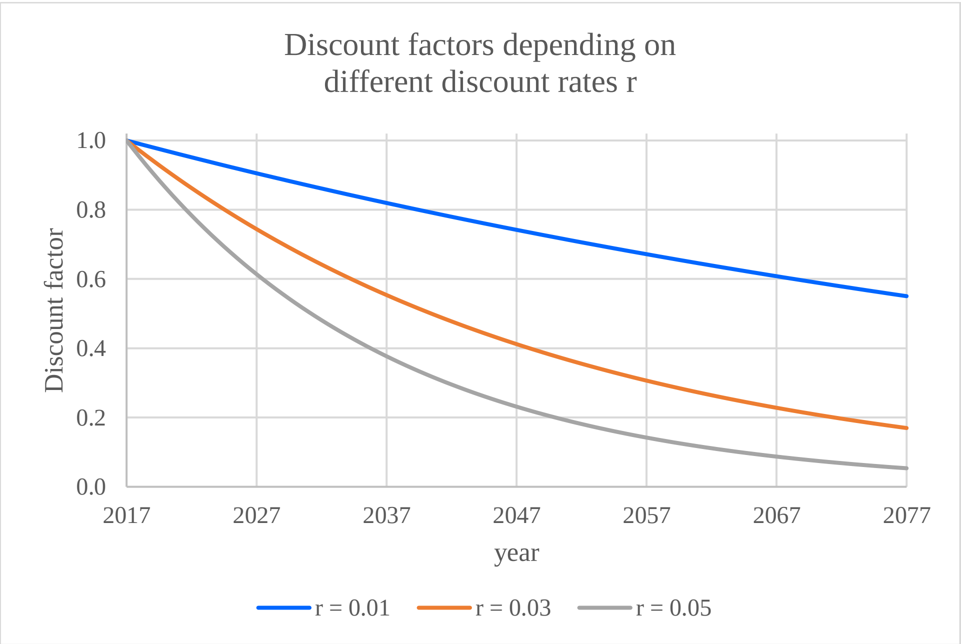

Figure 32: Discount factors depending on different discount rates

The impact from the different discount factors are examined on the five most beneficial designs. The mean and cumulated probability of benefit for a discount rate of r = 0.01 and r = 0.05 can be seen in Figure 33, respectively in Figure 34.

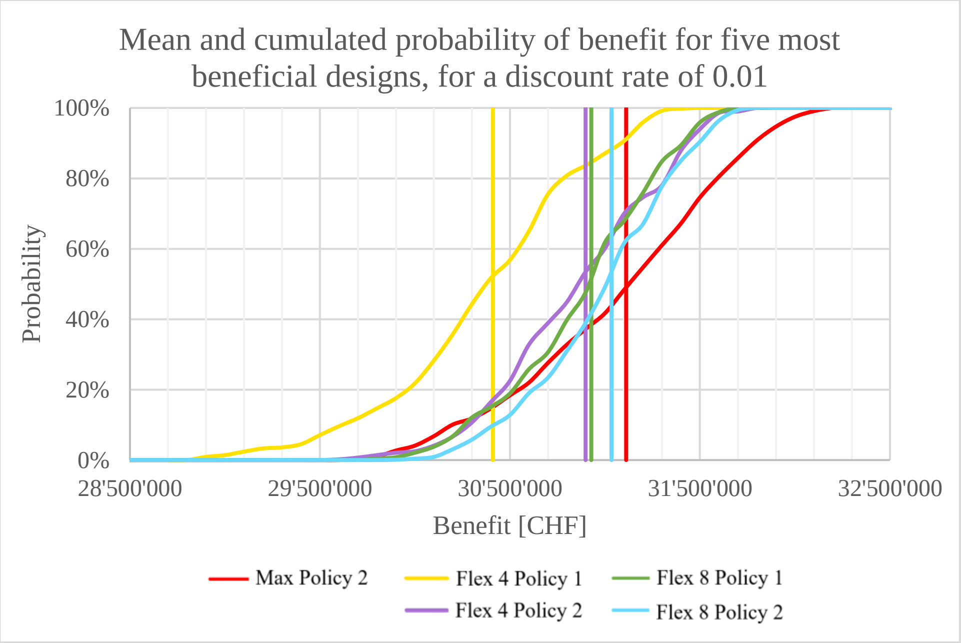

Figure 33: Mean and cumulated probability of benefit for five most beneficial designs, for a discount rate of 0.01

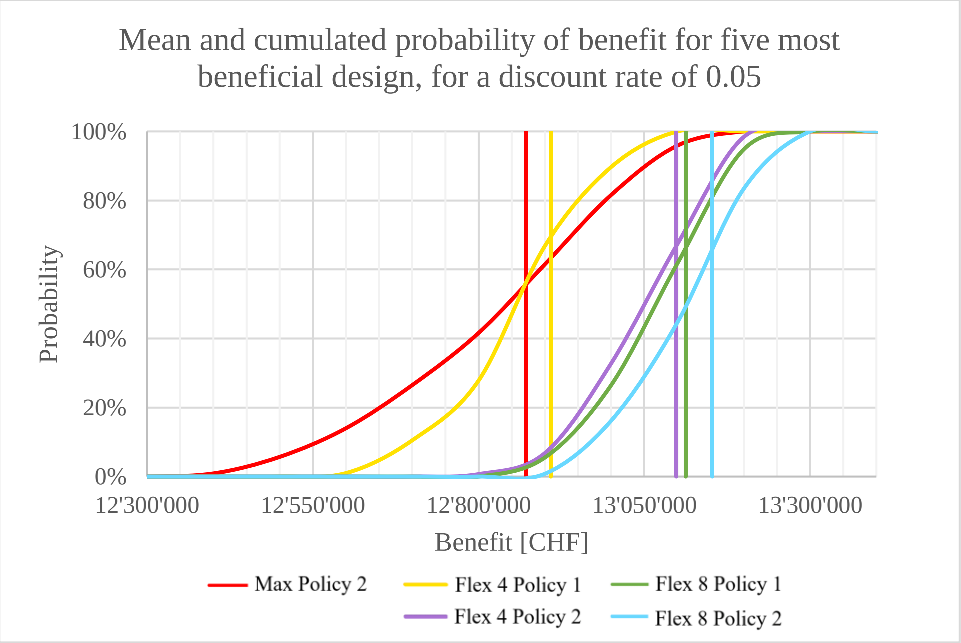

Figure 34: Mean and cumulated probability of benefit for five most beneficial designs, for a discount rate of 0.05

It can be seen, that the overall dimension of the benefits changes. For the lower discount rate, the range lays between roughly 28.5 Mio. CHF and 32.5 Mio. CHF, which is substantially higher than the benefit for the initial discount rate of 0.03. On the opposite, the range of the benefit for the higher discount rate is quite lower with 12.3 Mio. CHF to 13.3 Mio. CHF. This is because overall, the costs and benefits are less effective for the discount rate of 0.05, respectively more effective for a lower discount rate of 0.01. In Figure 33 and Figure 34 can be seen, that the order of the flexible design does not change throughout the different discount factors. The Flex 8 Design with Policy 2 is always the most beneficial flexible design, and the Flex 4 Design with Policy 1 is always the least beneficial flexible design. Therefore, the flexible designs are generally quite unaffected by a change in the discount rate. However, the position of the non-flexible Maximum Design with Policy 2 varies greatly. For a situation with a discount rate of 0.01, the Maximum Design with Policy 2 is the most beneficial design of all five. This is due to the fact, that the high initial costs of this design are not accounted as much because of the low discount rate, which leads to a higher overall benefit. On the other hand, with a discount rate of 0.05, the high initial costs of the Maximum Design are accounted even more in comparison to the costs in the following years. This leads to substantial decrease in benefit compared to the other designs.

7.2 Acceptance of EV users

Another aspect with great influence on the benefit and with high uncertainty is the acceptance of the EV users. There is a high probability, that the acceptance of the EV users are substantially lower than initially modelled. Therefore the benefits of the designs are estimated again with an adjusted acceptance of EV users. The adjusted user acceptance depending on the market share, can be seen in Figure 35. It is assumed, that the mean acceptance of the EV users lays at 50%, for a market share of 0 % ,and not at 80% as initially modelled. This will lead to a lower number of unsupplied EV users, which are still willing to stay at the parking garage. The impact on the benefits of the five most beneficial designs is shown by number in Table 10, and graphically in Figure 36. It can be seen, that all flexible designs are within the same order as for the initial assumption of the acceptance with just 170’000 CHF lower benefit on average for every design. The only exception is the Maximum Design with Policy 2. The benefit of this design has not changed much, because there aren’t any unsupplied EV users with this design. This drop in benefit for the flexible designs and the stability of the Maximum Design leads to the fact, that the Maximum Design with Policy 2 has more or less the same benefit as the Flex 8 with Policy 2.

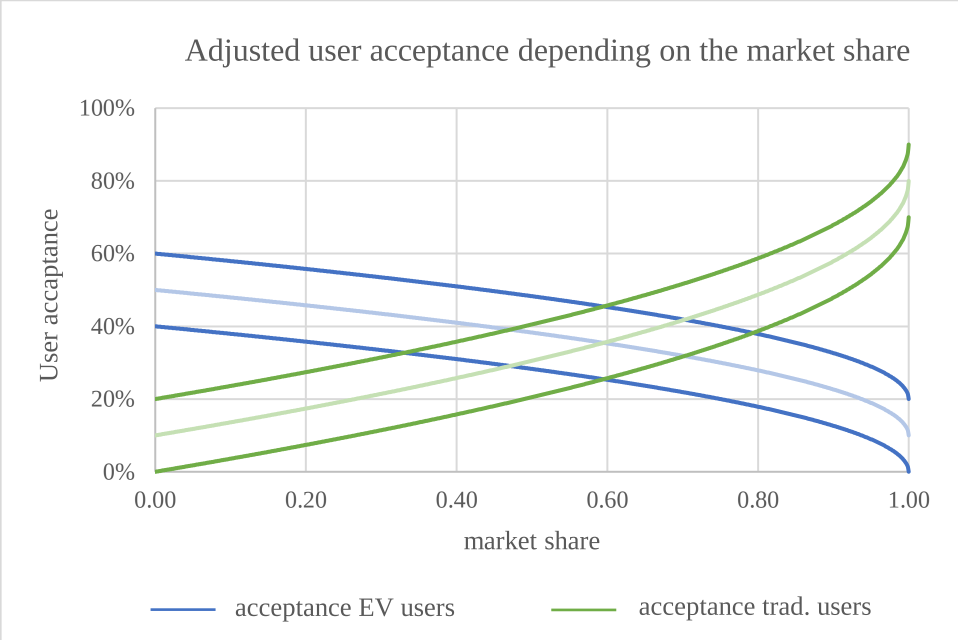

Figure 35: Adjusted user acceptance depending on the market share

Table 10: Mean and standard deviation of five most beneficial designs, with adjusted acceptance

Design	**Policy**	**Mean**	**Deviation**
Maximum	Policy 2	18'990'154 CHF	308'714 CHF
Flex 4	Policy 1	18'587'536 CHF	261'063 CHF
	Policy 2	18'877'638 CHF	241'897 CHF
Flex 8	Policy 1	18'930'868 CHF	208'182 CHF
	Policy 2	18'991'640 CHF	200'880 CHF

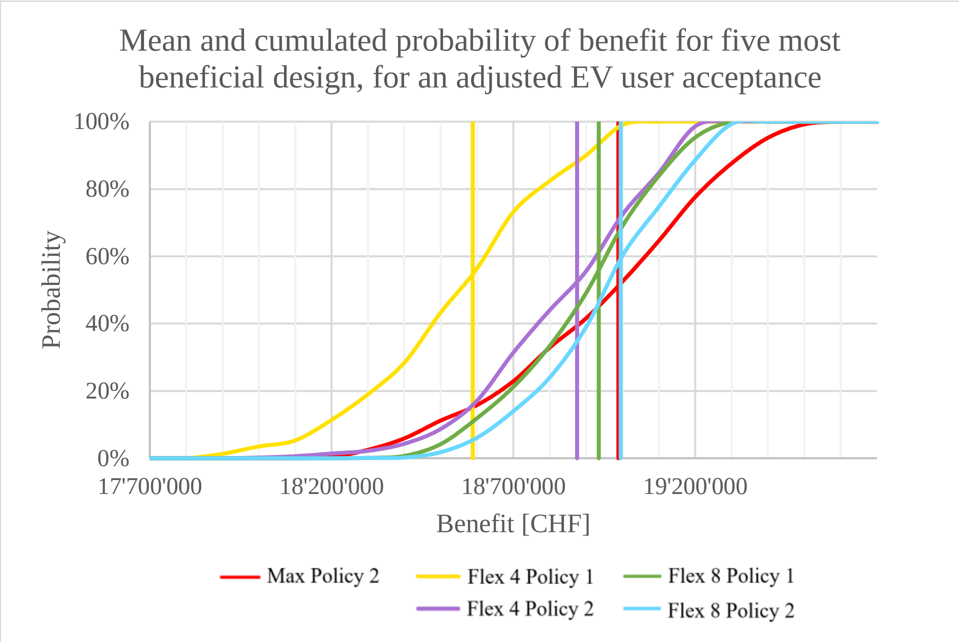

Figure 36: Mean and cumulated probability of benefit for five most beneficial designs, for an adjusted EV user acceptance

7.3 Initial costs for dimensioning the power provision

As a third sensitivity analysis the impact of higher initial costs is examined. The initial costs of a design are the most influencing costs on the benefit, since the discount factor is equal to 1 in the initial year. For the implementation costs just the cables, the empty conduits and the charging station are considered. However it is comprehensible, that there could be higher costs for the implementation of the charging facilities, especially regarding the electricity supply. For the implementation costs estimation done in section 5.8.1, possible costs for providing such a huge amount of electricity are neglected. These costs would pay for the electrical system needed, to bring the desired demand of electricity to the parking garage and to provide the electricity at ones (assumed, that all users would charge during the night). Since there isn't any reference data on the implementation of such a huge number of electrical charge facilities, the costs for such an electrical system can hardly be estimated. Nevertheless, to have a sense how the implementation of such an electrical system would affect the benefit a sensitivity analysis is carried out. To see the influence from the resulting higher initial costs, again 1000 simulations are made for each design, whereas all design, except the Traditional Design, have higher initial costs. In Table 6 it can be seen, that the implementation costs for all electrical parking spaces are 803'620 CHF. To see the effect, if the costs of a probably required electrical system are within the same dimension, the additional initial costs of 500'000 CHF are imposed on the designs. The difference between the mean of the benefit of the initially estimated initial costs and the mean with the higher initial costs of each design are shown in Table 11.

Table 11: Comparison between the mean of the benefit of each design with and without the additional initial costs of 500'000 CHF

Design	Policy	Mean without add. initial costs	Mean with add. initial costs
Traditional	-	16'084'702 CHF	16'084'702 CHF
Maximum	Policy 1	9'343'432 CHF	8'960'652 CHF
	Policy 2	18'977'275 CHF	18'490'154 CHF
Flex 4	Policy 1	18'787'131 CHF	18'273'201 CHF
	Policy 2	19'056'975 CHF	18'563'303 CHF
Flex 8	Policy 1	19'077'512 CHF	18'579'416 CHF
	Policy 2	19'137'521 CHF	18'640'187 CHF

It can be seen, that the overall situation of the designs and their benefits remains the same with the exception that every design has lower costs of roughly 500’000 CHF, which is the same amount as the additional initial costs. Only the benefit of the Traditional Design remains the same, since the Traditional Design does not require such an additional electrical system. Therefore, it can be said, that for a change in the initial costs, the benefits of the designs are changing uniformly, which leads to no difference in the order of the designs. Only in the situation, where the increasing in initial costs would exceed about 3.1 Mio. CHF, the Traditional Design would be more beneficial than the other examined designs. But since the initial costs are estimated to be 803’620 CHF for the parking garage with electrical charge facilities, it is quite unlikely that the additional initial costs for a probably required all system implemented, to provide the electricity, would cost more than 3.1 Mio. CHF.

8 Conclusion and outlook

Based on the results and the discussion in chapter 6, the Flexible Design with Policy 2 with an 8-step-implementation is determined to be the optimal design for the implementation of the examined parking garage. As it is seen in the chapter 6, it is indifferent how the market share is developing. The Policy 2 is always more beneficial than Policy 1. Therefore the application of Policy 2 is recommended. Furthermore an 8-step-implementation is suggested. An 8-step-implementation leads to more flexibility, and therefore less unsupplied users, which in turn leads generally to less loss in income and higher benefit. The Flexible Design with Policy 2 combines these two aspects, which makes it the most beneficial design. Additionally, the Flex 8 Design with Policy 2 has the lowest standard deviation of all examined ones, which again indicates the superiority of this design.

Furthermore, it can be seen, that the applied methodology, which is introduced in chapter 3, functions as intended and leads to a reasonable outcome. With the suggested methodology a more profound decision regarding the optimal design of the parking garage can be made. Additionally, it could be seen, that the flexible design is able to counteract the uncertainties of the future.

Throughout the sensitivity analysis in chapter 7 it becomes clear, that the Flexible Designs with Policy 2 with an 8-step-implementation is stable regarding the examined uncertainties of discount rate, acceptance and initial costs. In all three analyses the Flex 8 Design with Policy 2 is the most beneficial one out of all flexible designs. However, it is conspicuous, that at some cases the Maximum Design with Policy 2 can compete with the flexible designs. Actually, for the situation of a low discount rate the Maximum Design with Policy 2 is the most beneficial one from all examined designs. Nevertheless should the Maximum Design with Policy 2 not be preferred over the Flex 8 with Policy 2, because the Flex 8 Design is substantial more stable, more adaptable and has a higher benefit for the most examined situation. Furthermore, the time, in which the investment of the charging facilities is retaken through the rent is fairly lower for the Flex 8 Design. Additionally, the costs of one intervention for this design are lower and distributed more evenly throughout the examined 60-year-period. These two circumstances are surely preferred by investors and the owner.

Finally can be said, that this determination of the optimal implementation design of the examined parking garage, regarding the upcoming need of electrical charge facilities, needs to be valuated with care. Each step of the Real Option methodology is applied to the best of one's knowledge. Nevertheless, there is still a latitude within each estimated or assumed value. To improve the reliability of the models and estimation, the values need to be estimated with more competent knowledge. Experience from experts and form people within the corresponding industries is certainly recommended. Additionally, there are highly influencing aspects, which are neglected within this project work. For example the future handling of the electrical vehicle and how they are going to be charged is highly uncertain. There are suggestions, that the idea of a gas station should be maintained. But instead of gasoline the station would provide charged batteries for the electrical vehicle. The EV user can easily change the batteries and leave the empty ones at the station to charge for the next customer. This would make the implementation of charging facilities in the parking garage unnecessary. Furthermore, the assumption, that the demand of vehicles, regardless if traditional or electrical, will stay the same over the whole examined period is not realistic. Even at the current time there is the talk of automated vehicles. Their upcoming would lead to a decrease generally in parking spaces, which makes the parking garage useless. To include these mentioned aspects would however exceed the scope of this project work. Whereas at this point they are recommended to be considered for a further analysis.

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Annexes

A.1 Detailed calculation of the implementation costs

The material costs for the empty conduits are estimated to be 1.95 CHF/m. This estimation bases on the Spon's Mechanical and Electrical Services Price Book from 2015 (AECOM 2015), where the material costs for empty conduits are given as 1.50 £/m. With an exchange ratio of 1.30 CHF/£ (October 2018) the material costs for the empty conduits are 1.95 CHF/m as stated above. Analogue the material price of the cables can be determined. According to the Spon's Mechanical and Electrical Services Price Book from 2015 (AECOM 2015) the material costs of cables for this kind of use, are roughly 1.00 £ per meter. With an exchange ratio of 1.30 CHF/£ (October 2018) the material costs for the cables are 1.30 CHF/m.

It needs to be noticed, that there is no consideration about the possible change in price for the difference of the year 2015, where the data was generated, to the current state. It is assumed, that the estimations are, even without considering this change in price accurate enough for the scope of this project work.

A.2 Estimating the required length per parking space

To estimate the required length for cables and empty conduits per parking space, the required length to supply the whole level with electricity is determined. Generally can be said that firstly the conduits and cables are led within the ground from the charging station of each parking space to the next laying wall. Whereas only the parking spaces, which doesn’t boarder to a wall are assumed to have the need for the cables. From there, the cables are implemented to lead from the bottom of the wall to the ceiling. This length is assumed to be the height of the wall, which is circa 3 meters. Within the ceiling the cables are led to the next electrical supply station. Furthermore it is assumed, that throughout the whole level there are 6 electrical supply stations for the cables to go to, which leads to a required length of roughly 20 m on average per parking space. The length of the cables is indicated in Figure 37. The total length of the cables is rounded to 2000 m per parking level. With 115 parking spaces per parking level, the required length of cables and conduits per parking space is 17.4 meter.

The yielded length is just a rough estimation. For a further analysis the required cable length and electrical system should be estimated from a professional to have a more accurate calculation.